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TORONTO WATERFRONT GENERAL WATER QUALITY 1976 - 1983

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TORONTO WATERFRONT

GENERAL WATER QUALITY

1976-1983

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1.0 SUMMARY AND CONCLUSIONS

Water quality studies in the Toronto Waterfront from 1976 to 1983 have addressed a wide range of concerns, such as the influence of major sources of pollution (e.g. Don River, Main Sewage Treatment Plant) and the variability of water quality conditions with location and time. This report is restricted to general water chemistry and nutrients; heavy metals and trace organic contaminants will form the scope of an additional report now under preparation.

The major conclusions of these studies are as follows:

1. Water quality in the waterfront area varies with proximity to sources. Six water quality zones have been defined using cluster analysis for conventional pollutants. In decreasing order of impairment they are:

   i) the Keating Channel

   ii) the vicinity of the Main Toronto STP discharge (near Ashbridges Bay)

   iii) the northeast corner of the Inner Harbour (adjacent to the Keating Channel)

   iv) the remainder of the Inner Harbour

   v) the Outer Harbour and East and West Gaps

   vi) offshore waters.

2. In 1983, total phosphorus exceeded the Ministry guidelines of 0.02 mg/L in all zones but the offshore lake zone. The inner harbour total P of 0.027 mg/L represented a small and statistically insignificant decrease from 1977-78 (0.036 mg/L). If this reflects a true condition, it is probably attributable to the diversion of STP flows from the Don River to the York-Durham sewage system.

3. Ammonia levels exceed objectives of 0.02 mg/L as unionized NH_3 only near the Main STP outfall (0.075 mg/L) and in the Keating Channel (0.031 mg/L) with the Main STP outfall apparently the most important source.

4. Urban storm runoff via rivers and sewer outfalls has significant impact on waterfront water quality, especially in the Inner Harbour where influences from both the Don River and combined sewer overflows are present. The influence of runoff is reduced with increasing distance from shore.

5. No significant changes were observed from 1977 to 1983 in any parameter examined except for turbidity, which showed a significant decline. This is likely a result of reduced suspended solids loadings from the Main STP.

It is therefore concluded that further remedial action in the waterfront area should be directed towards reducing wet weather discharges from storm and combined sewers, to improving the quality of the Main STP effluent, and to investigating the sources of and solutions to water quality impairment in the Don and Humber Rivers.

2.0 INTRODUCTION

2.1 Description of Study Area

The Toronto central waterfront extends from Ontario Place in the west to Ashbridges Bay in the east, and includes the Toronto Inner and Outer Harbours, the Toronto Islands, the Outer Harbour East Headland Aquatic Park (headland), and the Lake Ontario shoreline areas immediately adjacent to the islands and headland (Fig. 1). The waterfront area has undergone considerable development, especially in the past few decades. A mosaic of numerous water uses influences the waterfront area. Consequently, numerous agencies at the federal, provincial and municipal level are involved in the regulation and control of water use in the waterfront. The history of the waterfront, development of the sewer system and lakefilling activity, water supply, industrial and recreational uses have all been summarized by Richardson (1980), and will not be further discussed except where they directly relate to harbour water quality and its recent trends.

The Inner Harbour is impacted by inputs from the Don River (via the Keating Channel) plus numerous storm and combined sewer overflows. Because the Toronto Inner Harbour is connected to the lake by the two separate channels, a harbour throughput of lake water occurs, generally from the West Gap to the East Gap. This throughput helps to ameliorate severe water quality degradation, as it has occurred in other Great Lakes areas such as Hamilton Harbour (Haffner, Poulton and Kohli 1982).

In the past, the only direct loading to the Outer Harbour has been the discharge from the R. L. Hearn Generating station, which was primarily water taken from the Turning Basin of the Ship Channel (Fig. 1) and warmed by the waste

heat from the generating station. As of fall 1983, this flow was terminated, except for occasional low-level (10% of capacity) pumping.

The Ashbridges Bay area is influenced most strongly by the Toronto Main STP discharge and several storm and combined overflow sewers, which, because of prevailing lake currents, can influence the quality of the lake water offshore of the headland.

2.2 Goals and Objectives of Study

Many items discussed in this report relate to the development of an effective management plan for the waterfront. These include inputs to the waterfront, eutrophication processes, effect of shoreline alterations, dredging, dredge spoils disposal. These issues have each been addressed by various Ministry studies. For example, the Toronto Area Watershed Management Strategy Study (TAWMS) began to identify the watershed inputs to the area in 1981, and has recently released an interim water quality report on the watershed area (MOE 1983). The Keating Channel dredging and lakefilling activity has been covered in a series of recent reports (Griffiths 1980, 1981; Griffiths and Winiecki 1981). These studies concluded that the effects of dredging at the Keating Channel and dredge spoil disposal and lakefilling at the headland were localized, and did not degrade the water quality at the waterfront nor was there any evidence of impacts from these on drinking water intakes.

This report describes the effects of discharges to the waterfront under dry and wet weather conditions using nutrients, turbidity and conductivity as indicators to delineate zones of effects. The spatial variations, runoff effects, seasonal and year-to-year trends discussed here should aid in understanding the processes governing other important water quality variables including toxic trace

contaminants and bacteria, which form the scope of other reports under preparation. Additionally, the data gathered here will serve as a baseline against which future changes can be compared.

2.3 Methodology and Data Bases Used

Results of several water quality surveys conducted in the Toronto Waterfront between 1976 and 1983 have been utilized in the preparation of this report. Spatial variations in harbour water quality were best defined by a series of intensive cruises conducted between 1976 and 1978, in which a large number of stations were sampled daily for three or four consecutive days. Survey dates are summarized in Table 1a. An additional 1983 cruise served to update the older data.

Data collected from several programs were combined in order to assess temporal trends. The Great Lakes spring nearshore surveys (1976-82) (Table 1b) provided coverage of most parts of the waterfront for several days each spring. The first four years of these surveys have been reported elsewhere (MOE 1980). These data also provided a baseline against which waterfront area data could be compared to assess the magnitude of the effect of human activities in the waterfront area.

The daily survey program and the Keating Channel dredging and dredge-spoil disposal programs (Table 1c) provided the largest data base for studying day-to-day, seasonal and year-to-year trends.

The first daily survey of Toronto Harbour (July 1968 to June 1969) was undertaken by the OWRC (Ontario Water Resources Commission) which, in 1972, was incorporated into the Ministry of the Environment. The chemical portion of the first six months of the survey was reported by Brydges (1969). Chemical, bacteriological and algal parameters were sampled from an Inner Harbour location between present stations 1357 and 1364, and from the R. C. Harris raw water intake east of the harbour. It was found that total phosphorus was the best indicator of runoff effects; nitrogen parameters tended to be affected by biological activity as well as runoff. Inter-parameter relationships were also found to be best defined by daily sampling.

The daily survey program was re-initiated in 1976 and continued until 1979, with a duration of between two and eight months per year. Stations sampled in each year, and the survey durations, are shown in Table 6. The purpose of the daily surveys was to define the range of variation in water quality due to short-term effects such as runoff, as well as seasonal and long-term (between-year) variations.

As part of the Keating Channel dredging and dredge spoil disposal study (Griffiths 1980; Griffiths and Winiecki 1981; Griffiths 1983), additional sampling was done in 1980 and 1981 one to three times per week at several background locations. These data were also used for trend testing, and are included in Table 6.

In 1980, several slip areas monitored by the joint MOE - Toronto City Works bacterial program were also sampled for nutrients and conductivity. These data were used to assess the impact of combined sewer discharges to semi-confined areas, and to compare these impacts to the effects observed in the Inner and Outer Harbours.

3.0 SPATIAL VARIABILITY

Between 1976 and 1978, a total of 13 multi-station cruises were conducted in the Toronto Harbour area (Table 1; Figure 1). As these cruises provided the best spatial coverage of recent years, they were used in order to define zones of relatively uniform water quality against which more recent variations in water quality could be compared.

The spatial variations were separated from the temporal variations using the analysis of variance method of El-Shaarawi and Kwiatkowski (1977), which produces a zonation map for each variable (chemical parameter) included. A common group of zones was defined by cluster analyses of the station effects for those parameters showing a significant ($P<0.05$) variation.

3.1 Dry Weather Conditions

Analyses were performed on the dry weather data in order to produce an average water quality zonation map against which other conditions could be compared. Data for 1976 were not used in this analysis, because most Outer Harbour and lake stations were not sampled for every cruise. The dry weather dates were selected by using meteorological and stormwater runoff data (see appendix), and when doubt existed (e.g. time of rainfall not stated), by looking at individual results. Dry weather dates selected were May 9-12/77, May 28-31/77, June 27-28/77, and May 27-June 1/78. The parameters chosen for analysis were ammonia, total Kjeldahl N, nitrite + nitrate-N, total P, FRP, silica, conductivity, turbidity, suspended solids, secchi disk and temperature.

The zones obtained are shown in Figure 2. Arranged in order by decreasing average water quality these are:

1. Lake locations most distant from man's activities (dredge spoil disposal sites, outfalls, etc.)

2. Outer Harbour plus lake locations closest to man's activities.

3. Inner Harbour except northeast corner, also including the Ship Channel and vicinity of the Hearn G.S. cooling water discharge.

4. Northeast corner of Toronto Inner Harbour.

5. Toronto Main STP outfall area.

6. Don River mouth or Keating Channel area.

In June 1983, an intensive survey cruise was conducted under dry weather conditions, in which 54 stations were sampled daily for three days in a manner similar to that of the 1976-78 cruises already discussed. The purpose of this study was to provide updated spatial variation of water quality which would improve the detection of long-term trends, and demonstrate the effect of abatement procedures such as the installation of the mid-town interceptor and diversion of several Don River watershed STP flows to the York-Durham system.

Data for total kjeldahl nitrogen, total phosphorus, conductivity, turbidity, suspended solids, secchi disk and chlorophyll a were processed by the methods already described. The resulting zonation map is shown in Figure 3. The six zones obtained are almost identical to those obtained in 1977-78 (Figure 2), although the statistical confidence of the zonation in Figure 3 is lower

because of the limited number of sampling dates and parameters. For this reason, minor changes in impacted zones, such as stations 1360 and 1362 being in zone 4 and 1543 in zone 5, should not be considered as indicating water quality degradation.

Average dry weather concentrations of various water quality constituents were calculated for the zones as defined above, for 1976 (Table 2), 1977-78 (Table 3) and 1983 (Table 4). Dry weather dates used for 1976 were May 4-5 (part of cruise 2), July 5-6 (part of cruise 4), August 4-6 and November 3-5. Thus the 1976 data represent an average from spring to fall, and the 1977-78 data (dates already stated) represent spring (May-June) values. The 1983 cruise was designed to be comparable seasonally to the 1977-78 dry weather cruises. However, it was more representative of early summer conditions due to unseasonably hot weather. For comparative purposes, some spring Lake Ontario nearshore data (MOE 1980) have been included in Table 5. These data represent zones near Toronto receiving little or no cultural impact, and are not intercomparable on a year-to-year basis due to changing zone boundaries.

Ammonia-N shows large variations (large standard deviations) and little or no distinction between harbour and lake zones (1-3). The source of such large variations appears to be caused by high-NH_3 water from the Main STP plume being carried westward along the headland and even south of the islands. Indeed, station 1540 near the southern end of the headland, nearly always shows ammonia values elevated above background (Table 5), with an average of 0.36 mg/L and a maximum of 0.69 mg/L during the 1977-78 dry weather surveys. At station 1536, south of the southern tip of the islands and near the Island filtration plant intakes, average ammonia-N was 0.11 mg/L and maximum was 0.35 mg/L. By contrast, locations further offshore and

less influenced by the Main STP plume, such as station 1544, reveal consistent ammonia levels of 0.01-0.02 mg/L, similar to values generally observed along the Lake Ontario nearshore. Similar effects are noticeable in the total Kjeldahl N data for these stations. This east to west transport is in accordance with average circulation patterns for the area derived from current meter measurements (Kohli 1983). Data for 1983 (Table 4) showed no significant differences from those of earlier years.

The Provincial Water Quality Objective of 0.02 mg/L for unionized ammonia is exceeded much of the time at the Keating Channel and Main STP outfall. At lake locations to the south and west of the Main STP outfall, the Objective was occasionally exceeded in 1978 due to the presence of high-NH_3 water from the Main STP plume as already stated, combined with a pH that was significantly higher in 1978 than in 1976. Other waterfront areas are predominantly in compliance with the Objective.

Nitrite plus nitrate-N shows values similar to open lake results, with enrichment due to Don River inputs and depletion in the zone adjacent to the Main STP outfall.

Total phosphorus levels in the zone 1 area of the lake (furthest from shore) are comparable to those of adjacent Lake Ontario areas with average concentrations at the Ministry guideline of 0.020 mg/L for prevention of algal nuisance problems in lakes. Progressively higher total P and FRP concentrations are found in other zones with the highest values adjacent to the major dry weather inputs at the Don River and Main STP. These areas are almost always in non-compliance with the Ministry guide- line. From 1977-78 to 1983, a significant decrease in total phosphorus occurred in zones 3 and 4 in the Inner Harbour, and zone 5 (Main STP outfall). Other zones showed no significant change. Although the 1983 data are too limited for a firm conclusion, they are in agreement with expected improvements due to abatement procedures such as the diversion in 1982 of STP effluents from the Don River to the York-Durham system.

Water clarity parameters (turbidity, suspended solids and secchi disk) show a strong distinction between all zones with the exception of zone 5. These results indicate water quality degradation due to inorganic turbidity from the Don River, combined sewer overflows, erosion, lakefilling activity and algal growth (see chlorophyll results, Tables 2 and 4). All zones are in excess of the Provincial Water Quality Objectives which state that the natural or background secchi disk reading should not be reduced by more than 10 percent. Although large inshore/offshore gradients were identified in the Lake Ontario spring nearshore surveys, likely as a result of the thermal bar, the comparison data (Table 5) confirm the large extent of water clarity degradation in the entire waterfront.

Conversely, the United States Environmental Protection Agency (USEPA) water quality criteria (quoted by Griffiths and Winiecki 1981) state that freshwater fisheries are affected only when suspended solids exceed 80 mg/L, a figure not reached except occasionally near the Keating Channel during runoff conditions.

Lakefilling activity and disposal of dredged material from the Keating Channel during 1980 and 1981 were shown to have a significant effect on turbidity and suspended solids near the dredge spoil disposal area along the outer headland (Griffiths 1980, 1983; Griffiths and Winiecki 1981). Turbidity plumes can exceed 2 km in length under high winds (above 20 km/h). Although the extent of filling in 1976-77 was less than that in 1980-81, (Richardson 1980, Figure 10), 0.45×10^6 m^3 in 1976 and 0.37×10^6 m^3 in 1977 compared with 1.44×10^6 m^3 in 1981 (Griffiths 1983), the filling likely contributed to the variability in turbidity and suspended solids at several zone 2 stations.

During the 1983 cruise, turbidity gradients, although still present, were not as pronounced as in earlier years, with significant decreases in turbidity and suspended solids except in zones 1 and 5. This decrease may have been partly due to the long spell of warm dry weather preceeding the 1983 cruise (last previous significant rainfall was on June 6). More data are needed to verify the decrease.

The influence of inorganic turbidity in Toronto Harbour is also indicated by comparing average secchi disk depths and chlorophyll values to the statistical relations developed for these parameters and total phosphorus in the open waters of the Great Lakes (Chapra and Dobson 1981). Using the data in Table 2, the relation predicts secchi depths approximately 50 percent greater than observed values in zones 2 and 3, thus indicating the importance of inorganic turbidity in both the harbour and nearshore lake areas. In turn, if chlorophyll values are estimated from total phosphorus averages, the observed chlorophyll averages are 20 to 40 percent lower than predicted. Limitation of light absorption by inorganic particles, toxicity or other cause is suggested. This topic is considered to be beyond the scope of present discussion.

3.2 Water Quality During Runoff Periods.

The impact of runoff which occurred during cruise periods in 1976-78 was highly variable, with each runoff period having a different impact upon the waterfront area water quality. This is likely due to influences of wind and lake circulation, as well as the amount and geographical distribution of rainfall and runoff. Details of water quality changes observed are given in Appendix A.1, together with rainfall, Don River runoff and combined sewer overflow (CSO) data. The results obtained from automatic water quality monitors in 1977 and 1978 also defined changes occuring during runoff periods. These are detailed in Appendix A.2.

As expected, the Inner Harbour is by far the most severely affected area from runoff. The Outer Harbour is affected primarily by substances transported from the Inner Harbour through the East Gap or the Hearn ship canal. Direct influences on the lake are minor or non-existent, with the strongest effect of runoff there perhaps being turbidity and suspended solids eroded from the headland or other shoreline areas. Effects of the Main STP depend on variables such as lake currents, as well as runoff. They are described in more detail in a separate report.

The parameter most highly influenced by runoff is turbidity (plus the associated clarity parameters suspended solids and secchi disk). A sample distribution of turbidity is shown in Figure 4. This figure shows high turbidity input from the Don River being transported along the east side of the Inner Harbour, and through the East Gap and ship channel to the Outer Harbour. At other times, turbidity is observed to be concentrated along the north shore of the Inner Harbour, or transported along the island shoreline (see Appendix A.1).

Effects of runoff are also observed with nutrients (primarily total P) and conductivity. Although the numerical model of harbour circulation (Poulton 1980) predicted that runoff effects would disappear within a day of cessation of runoff, effects were usually observed on the second day as well. This probably occurred because conductivity was chosen as a model parameter; this parameter shows a "first flush" effect with a peak early in the runoff and low values, often below ambient harbour levels, at and immediately after the flow peak (see Appendix A.2). Suspended material, on the other hand, continues to be transported throughout the entire runoff.

4.0 TEMPORAL VARIABILITY

The Toronto waterfront exhibits a mosaic of temporal scales of variability in water quality, ranging over periods of the order of minutes to years. The shortest intervals (minutes to hours) were studied by automatic water quality monitors from 1975 to 1979 (Poulton 1977a; see also Appendix A.2). The present discussion will focus on seasonal and annual variability. All trends are discussed in relation to the water quality zones as already defined (Figures 2 and 3).

4.1 Dry Weather Conditions

Of primary interest for water management issues are year-to-year trends, which help to define the effectiveness of abatement processes in improving water quality, as well as indicating areas of concern regarding deteriorating water quality. A brief mention of seasonal trends is also made.

As no single data base included a complete set of results for all years, trend testing was done separately using spring survey data and daily survey data.

4.1.1 Spring Survey Data

Data obtained during dry weather cruises of April-May 1976 to 1978 and June 1983 were combined with the results of the spring Great Lakes survey cruise stations within the Toronto waterfront area between 1977 and 1982 to obtain a data base for examining year-to-year trends (Tables la-b). Great Lakes survey cruise stations not used in the 1976-78 cruises were placed in the best estimate of the water quality zone (Figure 2) corresponding to the station location, and results obtained under runoff conditions were dropped. Data from the 1969 daily survey between April 1 and May 31 representing dry weather were used to extend the comparison to earlier years.

Results for ammonia, total phosphorus and conductivity in zones 1 and 3 from 1969 to 1983 are plotted in Figure 5. Both large within-year variations and random between-year changes are observed with ammonia and conductivity. Although total phosphorus shows a small decreasing trend from 1977 to 1983 in both the lake and Inner Harbour, the variability is great enough to render the significance of this short a time span doubtful. The decreasing trend for total phosphorus is, however, confirmed by inclusion of the 1968-69 daily data as discussed later.

Data for the highly impacted zones 4 to 6 are far too variable and span too few years (3 to 4 at most) for analysis.

4.1.2 Daily Survey Data

Between-year trends were examined by linear regression of monthly means after removal of seasonality. This method was similar to that used for trend analysis of Nanticoke water chemistry data (Polak 1978), except that monthly means were used rather than mid-month interpolated values. Runoff data were separated from dry weather data for those parameters and stations where the t-test of differences between wet and dry means (see section 4.2.1) was significant for at least two years.

The limited number of years for which adequate daily data were available (1977-1981; Table 1c) made determination of significant trends difficult and subject to error due to possible cyclical tendencies. Data for 1976 were not used because of the short period of measurement (two months).

The results of these trend tests are given in Table 6. The time series from 1977 to 1981 was too short for the adequate determination of significant trends. The only

significant changes found were: turbidity decreased at stations 202 and 1364, secchi disk depth decreased at station 1536, and chlorophyll a increased at all three stations. For longer-term detection of significant trends, these data were compared with 1968-69 data using a t-test. As shown in Table 6, a larger number of significant trends were found.

The large apparent turbidity decrease from 1968-69 to more recent years is at least partly due to an instrumentation change in 1973 from the Hellige turbidimeter to the Hach turbidimeter, which is far more sensitive at low turbidities (M. Rawlings pers. comm.). A portion of the decrease is likely real, as Main STP effluent suspended solids concentrations decreased from 30 to 40 mg/L in the late 1960s to 15-20 mg/L in the early seventies and a 1976-81 average of 11 mg/L.

The significant increasing trend for chlorophyll a between 1978 and 1981 is illustrated by plots of monthly means against date for stations 1364 and 1536 in Figure 6. The solid lines are the linear regression lines and the dotted lines indicate the 95% confidence limits for the slopes of the lines. This increase is surprising in view of the observed decrease from 1968-69 to 1977, seen in both these data and in the Lake Ontario nearshore data (MOE 1980). Results for station 1364 suggest a possible cyclical trend, as 1981 values decreased from the 1980 maximum. Only continued monitoring will indicate whether a maximum has been reached, or whether chlorophyll a concentrations are continuing to increase.

Secchi disk depth exhibited a minor, but barely significant decrease from 3.2 m in 1977 to 2.7 m in 1979, and remained constant from 1979 to 1981. This apparently correlates with the increase in chlorophyll a. Other explanations for this change are not evident.

Nitrate plus nitrite-N showed an increasing trend in both harbour and lake areas between 1968-9 and 1977. This increase has been generally observed in the Lake Ontario nearshore region (MOE 1980); however, no indication of continued increase was evident between 1977 and 1982.

Total phosphorus has apparently reached an equilibrium value in the waterfront area. This is expected since loadings to the waterfront area have remained relatively constant since phosphorus removal was begun at the Main STP in 1976. The significant decrease of 9 % per year in the Inner Harbour between 1968-69 and 1977 reflects the effect of phosphorus removal and detergent phosphorus limitations introduced in the early 70s. This decrease is in agreement with observations in the Lake Ontario nearshore area (MOE 1980). Although largely a whole-lake effect, decreased loadings at the Main STP and Don River also contributed to the decrease (Figures 7 - 8). Loadings from the Main STP (Figure 7) show a maximum in 1970 just prior to the start of detergent reformulation, with effluent total phosphorus concentrations dropping to average values of 1.0 mg/L or lower since 1976 as a consequence of P removal. A similar decrease in phosphorus loadings in the Don River resulting from phosphorus removal at several sewage treatment plants is shown in Figure 8 (Chin, Lammers and Oles 1981, with 1980-82 data from J. Eddie personal comm.). Three of the remaining four STPs in the Don River watershed (Pugsley, North Don and John Street) were removed in the fall of 1981, and their sewage flow diverted to the York-Durham system (MOE 1983). Resultant further decreases in P loading in the Don have produced a small decrease in average Inner Harbour phosphorus concentration, as revealed by the results of June 1983 measurements (Table 4). Further measurements to confirm this decrease would be desirable, as no significant difference was found at the mouth of the Keating Channel (zone 6, Table 4), and this parameter does exhibit considerable day-to-day variability as will be discussed later (Figure 10b).

4.1.3 Seasonal Effects as Indicated by Daily Surveys

Unlike Hamilton Harbour, which shows considerable seasonal variations in numerous parameters related to variations in biological and physical processes (MOE 1981), Toronto Harbour shows distinct seasonal cycles in only a few parameters. This factor is related to the rapid flushing (average residence time <10 days) and shallow water depth of Toronto Harbour relative to Hamilton Harbour (Haffner, Poulton and Kohli 1982), as well to short-term effects such as runoffs. Consequently, only weak thermal stratification and occasional minor dissolved oxygen deficits develop, as seen in a biweekly series of profiles taken at station 1364 in 1977 (Figure 9). Only during a late summer period of intense downswelling did a significant DO depletion occur.

Nitrate plus nitrite-N showed a general pattern of decline towards a summer (July-September) minimum, followed by a gradual fall increase. Summer minimum values show a series of fluctuations (Figure 10a). The general trend roughly parallels that of Lake Ontario (Shiomi and Chawla 1970) as might be expected from the fast flushing rate of the harbour. Phytoplankton uptake and decay is likely the main regulatory factor for this parameter.

Total phosphorus concentrations fluctuate randomly with no discernable seasonal trend (for example station 1364 in 1980, Figure 10b). The scatter indicates that factors other than runoff must be important in controlling the concentrations of total phosphorus.

Conductivity shows a decrease from a spring maximum caused by spring runoffs, including road salts (for example, station 1364 in 1979, Figure 11). The smaller increase in late summer and fall may be caused by evaporation exceeding input by precipitation.

Although a tendency towards higher spring and fall values is apparent, the variation of chlorophyll *a* (station 1364 in 1979, Figure 12) is generally irregular. This is obviously a function of the short residence time which results in dilution and outward transport of nutrients, and thus provides little opportunity for an indigenous response to the prevailing nutrient loadings.

4.2 Runoff Conditions

4.2.1 Comparison of Wet and Dry Weather Data by Daily Surveys

One of the major purposes of the daily survey program was to improve the definition of the significance and magnitude of the effect of runoff on various parts of the harbour. To achieve this objective, daily data from stations 1364 (Inner Harbour, zone 3), 202 (Outer Harbour, zone 2), and 1536 (Lake Ontario, zone 1) were analyzed. These data were broken down into "wet" and "dry" samples on the basis of Don River streamflow data, augmented by City of Toronto stormwater runoff data and rainfall data where necessary. The Don River data were chosen as the primary determinant since these were available at hourly intervals, and rapidly indicated an impact due to rainfall anywhere in the watershed. This procedure was also applied to the parameters used in year-to-year trend analysis.

The significance of the runoff effect was determined by a "t" - test of the hypothesis that the means of wet and dry data are equal. The SAS statistical package was used for all tests (Helwig and Council 1979). Tests were performed for each year (1977-81) individually, and all years grouped together. Station 1419 was not tested as it was felt that variability in Main STP plume characteristics due to physical effects like wind and currents were more important than runoff effects. Test results are given in Table 7.

As could be expected, effects of runoff were generally not significant at station 1536 (lake). Testing of all five years data together, however, did indicate a significant ($P<0.05$) effect for total P and turbidity, probably influenced by the increased number of degrees of freedom caused by combining years. In 1977, nitrate plus nitrite and conductivity were actually higher under dry weather conditions at both stations 202 and 1536. This difference appeared to be caused by low values which occurred for several consecutive days in early August during a prolonged runoff event and may have indicated rainwater dilution. Low values were also seen at station 1364 but the difference was not statistically significant.

In the Inner Harbour at station 1364, significant effects of runoff were found for all parameters except conductivity and chlorophyll a. As runoff events frequently introduce water of reduced conductivity after the "first flush" of high conductivity has passed (Poulton 1977a, 1977b, 1980; Appendix A.2), the lack of a significant difference for conductivity is explained. In agreement with 1976-78 cruise data (Appendix A.1), the most significant effects occurred for total P and turbidity. Ammonia, by comparison, was highly variable, with concentration peaks sometimes occurring up to three or four days after a runoff. Uncorrelated peaks were also found occasionally. These data indicate other variables besides runoff are important in controlling Inner Harbour water quality.

Statistical tests reveal that significant effects of runoff in the Outer Harbour at station 202 are almost as strong as in the Inner Harbour, though the differences between wet and dry means are not as great. Again, the largest effect occurs with turbidity and total phosphorus.

4.2.2 Effects of Runoff as Observed in Slip Areas

As many of the storm and combined sewer overflows discharge into semi-enclosed slip areas, these provide an opportunity for enhanced definition of the effects of runoff. It is for this reason that these areas are used in bacterial programs such as the joint MOE-Toronto City Works program.

In 1980, this program included monitoring for various nitrogen and phosphorus forms and conductivity at one stormwater discharge each to Inner Harbour (3002), Keating Channel (3004), Outer Harbour (3005), and Humber Bay. The locations of the first three discharges plus the other CSO overflow points to the harbour (monitored for bacteria only) are shown in Figure 13. Data were obtained twice a week for most of 1980. Although the dates of the two separate programs did not coincide exactly, they still allowed a comparison of water quality conditions in the slip and open water areas of the harbour.

Water quality at the Simcoe St. slip (station 3002) is compared with the Inner Harbour in Figure 14. During dry weather intervals, water quality in the slip is very similar to that in the harbour. This indicates that no significant dry weather flows are occurring, i.e. all sewage flows are being diverted by the interceptor sewers. Under runoff conditions, higher peak concentrations are observed at the slip. These peaks are highest for total phosphorus, compared to either nitrate-N or conductivity. This is consistent with the impact of runoff on total P discussed elsewhere.

In the winter and early spring, most parameters at the slips show slightly higher average concentrations. This could be due to reduced biological assimilation of nutrients, and road salt input in the case of conductivity. The conductivity maxima coincide with

melting conditions (February 18) following a snowfall on February 15-16, and a snowfall at temperatures just below freezing (March 13). These show a definite impact of road salt on the slip areas.

Figure 15 shows total phosphorus results in the Outer Harbour. In this case, baseline station 3005 values are slightly higher than mid-harbour (station 202) values, corresponding roughly to the Inner Harbour (zone 3) mean. This is undoubtedly the effect of Inner Harbour water being drawn through the Hearn G.S., and agrees with the zonation of station 1394 at the same point in 1977-78 (Figure 2).

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TABLES 1a to 7

FIGURES 1 to 15

TABLE 1a

INTENSIVE SURVEY CRUISE DATES - TORONTO HARBOUR

YEAR	CRUISE NUMBER	CRUISE DATE	NO. OF STATIONS
1976	1	March 31 - April 3	61
	2	May 4 - 6	14
	3	June 29, 30	14
	4	July 5 - 9	87
	5	August 4 - 6	14
	6	November 3 - 5	26
1977	1	May 9 - 12	57
	2	May 28 - 31	27
	3	June 27 - 29	27
	4	September 1 - 3	28
	5	November 7 - 10	29
1978	1	May 27 - June 1	69
	2	Sept. 29 - Oct. 3	62
1983	1	June 22 - 24	51

TABLE 1b

SPRING NEARSHORE SURVEYS, 1976-1982

YEAR	SURVEY DATES	NO. OF STATIONS
1976	760504 - 760505	3
1977	770419 - 770421	19
1978	780426 - 780429	18
1979	790419 - 790430	24
1980	800424 - 800520	25
1981	810411 - 810504	24
1982	820419 - 820504	25

Note: Data from intensive cruises (Table 1a) collected in April and May of 1976-78 were also used in statistical calculations.

TABLE 1c

Daily Survey Stations, Toronto Harbour

Year	Stations	Dates
1968	TH-1 (1364), LO-6 (1872)	680710-681220
1969	TH-1 (1364), LO-6 (1872)	690106-690711
1976	202,1364,1872	760705-760903
1977	202,1364,1536	770510-770816
1978	202,1364,1419,1536	780516-781114
1979	202,1364,1536	790417-791207
1980	202,1364,1379,1419,1536,1733,1872	800512-801125
	plus MOE-City Works stations	
	3002,3004,3005,3007	800103-801120
1981	202,1364,1379,1419,1536,1872	810430-811112

Note: 1980 and 1981 data were collected once to three times a week as part of the Keating Channel dredging and dredge spoil disposal program. Water chemistry data were also collected twice a week in 1980 as part of the joint MOE-Toronto City Works bacteriological monitoring program at the stations indicated.

TABLE 2

TORONTO HARBOUR WATER QUALITY DATA, 1976 DRY WEATHER CRUISES

MEAN BY ZONE FOR WATER QUALITY PARAMETERS

UPPER NUMBER - MEAN

LOWER NUMBER - STANDARD DEVIATION

UNITS ARE MG/L UNLESS STATED OTHERWISE

PARAMETER	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	PWQO
NH3-N	-	0.077	0.129	0.26	-	0.56	
	-	0.096	0.111	0.12	-	0.23	
Unionized	-	0.0008	0.0009	0.0009	-	0.0008	0.02
NH_3	-	0.0015	0.0008	0.0003	-	0.0002	
TKN	-	0.42	0.50	0.69	-	1.10	
	-	0.16	0.13	0.17	-	0.44	
NO2+NO3-N	-	0.25	0.32	0.58	-	0.93	
	-	0.10	0.16	0.46	-	0.98	
TOTAL P	-	0.031	0.040	0.066	-	0.103	0.02
	-	0.013	0.012	0.023	-	0.056	(GUIDELINE)
TOT FILT P	-	0.020	0.023	0.033	-	-	
	-	0.003	0.003	0.007	-	-	
FRP	-	0.009	0.011	0.023	-	0.052	
	-	0.006	0.007	0.012	-	0.033	
Si	-	0.197	0.30	0.79	-	4.15	
	-	0.107	0.22	0.76	-	-	
CONDUCTIVITY	-	347.	364.	433.	-	513.	
(UMHO/CM)	-	20.	30.	82.	-	207.	
pH	-	7.37	7.41	7.29	-	7.09	6.5-8.5
	-	0.25	0.23	0.11	-	0.12	
CHLORIDE	-	30.9	33.7	46.4	-	63.2	
	-	3.7	4.8	16.4	-	36.6	
TURBIDITY	-	2.34	3.04	5.78	-	8.4	
(FTU)	-	1.21	1.19	3.43	-	5.5	
SUSP SOLIDS	-	-	5.50	-	-	10.3	
	-	-	1.05	-	-	6.5	
SECCHI DISK	-	1.70	1.38	0.92	-	0.66	< 10%
(M)	-	0.85	0.57	0.45	-	0.36	DECREASE
CHL a	-	6.37	8.7	8.7	-	5.20	
(UG/L)	-	3.15	3.5	3.5	-	-	

TABLE 3

TORONTO HARBOUR WATER QUALITY DATA, 1977-78 DRY WEATHER CRUISES
MEAN BY ZONE FOR WATER QUALITY PARAMETERS

UPPER NUMBER - MEAN
LOWER NUMBER - STANDARD DEVIATION
UNITS ARE MG/L UNLESS STATED OTHERWISE

PARAMETER	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	PWQO
NH_3-N	0.099 0.115	0.095 0.134	0.094 0.081	0.34 0.30	2.56 2.38	1.79 1.22	
UNIONIZED* NH_3-N	0.016 0.016	0.007 0.014	0.004 0.004	0.012 0.009	0.075 0.083	0.031 0.035	0.02
TKN	0.39 0.17	0.46 0.17	0.50 0.13	0.89 0.38	3.52 2.50	2.49 1.13	
NO_2+NO_3-N	0.28 0.02	0.31 0.03	0.33 0.05	0.45 0.12	0.23 0.03	1.10 0.84	
TOTAL P	0.020 0.007	0.028 0.013	0.036 0.020	0.057 0.027	0.123 0.085	0.161 0.081	0.02 (GUIDELINE)
TOT FILT P	0.010 0.004	0.011 0.006	0.013 0.005	0.021 0.014	0.060 0.066	0.096 0.069	
FRP	0.004 0.003	0.005 0.006	0.005 0.004	0.010 0.013	0.033 0.041	0.071 0.062	
Si	0.080 0.037	0.065 0.028	0.087 0.090	0.29 0.38	0.49 0.33	4.15 1.38	
DOC	3.81 2.08	4.51 2.79	4.25 2.42	4.62 1.92	5.53 3.02	6.47 2.58	
CONDUCTIVITY (UMHO/CM)	338. 8.	358. 19.	377. 21.	448. 55.	453. 85.	845. 231.	
pH*	8.7 0.1	8.6 0.3	8.7 0.2	8.5 0.2	8.3 0.7	7.97 0.18	6.5-8.5
CHLORIDE	29.9 1.7	34.2 3.7	39.0 6.4	54.4 12.8	52.6 14.4	138. 54.	
TURBIDITY (FTU)	0.94 0.37	1.76 0.86	2.12 1.36	3.70 3.45	2.12 1.26	14.2 6.9	
SUSP SOLIDS	1.67 0.54	2.94 1.14	4.21 2.08	7.75 4.84	3.95 2.03	26.6 8.9	
SECCHI DISK (M)	3.19 1.44	1.88 0.70	1.40 0.36	0.99 0.31	1.49 1.15	0.32 0.17	< 10% DECREASE

Note* 1978 only.

TABLE 4

TORONTO HARBOUR WATER QUALITY DATA, JUNE 1983

MEAN BY ZONE FOR WATER QUALITY PARAMETERS

UPPER NUMBER - MEAN
LOWER NUMBER - STANDARD DEVIATION

UNITS ARE MG/L UNLESS STATED OTHERWISE

PARAMETER	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	PWQO
TOTAL KJELDAHL N	0.36 0.13	0.45 0.08	0.53 0.09	0.75 0.25	2.12 2.53	2.97 1.00	
TOTAL P	0.018 0.006	0.024 0.007	0.027 0.006	0.039 0.015	0.054 0.057	0.191 0.047	0.02 (GUIDELINE)
TURBIDITY (FTU)	1.08 0.44	1.23 0.71	1.74 0.56	2.57 1.55	1.80 0.82	9.2 2.6	
SUSP SOLIDS	1.28 0.41	1.77 1.05	2.68 0.56	3.56 1.79	2.28 1.26	12.6 2.9	
SECCHI DISK (M)	3.57 1.04	2.96 0.67	2.18 0.40	1.67 0.50	3.17 0.40	1.33 1.79	< 10% DECREASE
CONDUCTIVITY (UMHO/CM)	349. 5.	351. 6.	373. 10.	418. 32.	365. 9.	958. 38.	
CHLOROPHYLL *a* (UG/L)	3.01 1.17	4.99 1.93	8.33 2.65	7.40 1.71	1.43 0.92	4.63 2.50	
CORR CHLOR *a* (UG/L)	2.64 1.18	4.45 1.80	7.36 2.41	6.23 1.18	1.35 0.91	3.93 2.14	

TABLE 5

Spring Nearshore Lake Ontario Averages

Non-Impacted Areas (MOE 1980)

units are mg/L unless otherwise indicated

Parameter	1976		1977		1978		1979	
	mean	sd	mean	sd	mean	sd	mean	sd
NH_3-N	.016	.008	.011	.004	.015	.008	.025	.033
NO_2+NO_3-N	.293	.016	.297	.017	.322	.016	.349	.02
Total P	.020	.003	.019	.007	.016	.003	.017	.002
FRP	.004	.001	.007	.001	.007	.002	-	-
Si	.272	.050	.104	.031	.166	.037	.238	.065
Conductivity (umho/cm)	330	6	347	18	326	4	349	10
secchi depth (m)	5.5	.35	6.9	.58	6.0	.49	6.9	.80
chlorophyll *a* (ug/L)	2.6	.65	-	-	2.1	.47	3.6	.81

TABLE 6

Determination of Year-To-Year Trends From Daily Survey Data, Toronto Harbour, 1968-69 to 1977-81

Station	Parameter	1977-1981 No. of Years	No. of Samples	Mean Value	Rate of change % of mean value per year	1968-1977 1968-69 Mean	"t" Value	% change per year
202	NH_3-N	4	234(D)	.059	NS	-	-	-
		4	139(W)	.079	NS	-	-	-
	(NO_2+NO_3)-N	4	378(T)	.29	NS	-	-	-
	Total P	5	267(D)	.030	NS	-	-	-
		5	152(W)	.035	NS	-	-	-
	conductivity	5	317(T)	358	NS	-	-	-
	turbidity	5	195(D)	1.76	-7.1%	-	-	-
		5	126(W)	1.96	NS	-	-	-
	secchi disk	5	210(D)	2.0	NS	-	-	-
		5	124(W)	1.8	NS	-	-	-
	chlorophyll a	4	326(T)	9.3	+9.4%	-	-	-
1364	NH_3-N	4	240(D)	.080	NS	.087	NS	-
		4	139(W)	.104	NS	.243	2.96**	-7.2%
	(NO_2+NO_3)-N	4	374(T)	.31	NS	.21	5.69**	+6.1%
	Total P	5	270(D)	.035	NS	.110	22.2**	-8.5%
		5	152(W)	.040	NS	.133	16.1**	-8.7%
	conductivity	5	309(T)	359	NS	379	NS	-
	turbidity	5	189(D)	1.8	-9.3%	6.1	10.9**	-10.4%
		5	127(W)	3.1	-18%	10.0	6.5**	-8.6%
	secchi disk	5	211(D)	2.0	NS	-	-	-
		5	127(W)	1.5	NS	-	-	-
	chlorophyll a	4	321(T)	9.3	+8.9%	26.0	8.90**	-7.6%
1536	NH_3-N	4	355(T)	.071	NS	.061	NS	-
	(NO_2+NO_3)-N	4	356(T)	.25	NS	.16	5.85**	+5.2%
	total P	5	402(T)	.023	NS	.032	5.19**	-4.4%
	conductivity	5	300(T)	336	NS	331	2.92**	+0.2%
	turbidity	5	314(T)	1.4	NS	3.3	6.92**	-7.7%
	secchi disk	5	327(T)	3.0	-7.1%	-	-	-
	chlorophyll a	4	305(T)	4.8	+10.8%	8.2	3.44**	-3.8%

Note: Mean values for N and P are in mg/L, conductivity in umho/cm, turbidity in FTU, secchi disk in m, and chlorophyll a in ug/L.
* Significant at P <0.05
** Significant at P <0.01
NS = not significant
(T) = total data set used
(D) = dry weather data set used
(W) = wet weather data set used
Station 1536 is compared with 1968-69 station LO-6 (R.L. Harris intake), as the chemical environment is probably similar at the two locations.

TABLE 7

T-Tests of the equality of means of daily data collected under wet and dry conditions

Station	Parameter	1977	1978	1979	1980	1981	Combined 1977-81
202	NH_3	NS	NS	-2.49*	NS	-	-3.49**
	NO_2+NO_3	2.23*	NS	NS	NS	-	NS
	Total P	-2.09*	-2.99	-2.64**	NS	-2.40*	-5.65**
	Conductivity	2.24*	NS	-2.91**	NS	-	NS
	Turbidity	-2.47*	NS	-2.66**	-2.54*	NS	-4.12**
	Secchi disk	2.24*	NS	2.48*	NS	NS	3.58**
	Chlorophyll *a*	-	NS	NS	NS	NS	-2.47*
1364	NH_3	NS	-2.29*	NS	-2.31*	-	-3.66**
	NO_2+NO_3	NS	NS	NS	-3.17**	-	NS
	Total P	-4.03**	-3.54**	-2.35*	-2.76**	-2.66*	-7.75**
	Conductivity	NS	NS	NS	NS	-	NS
	Turbidity	-3.89**	-	-4.44**	-2.48*	NS	-6.75**
	Secchi disk	3.47**	NS	NS	2.99**	NS	2.11*
	Chlorophyll *a*	-	NS	NS	NS	NS	NS
1536	NH_3	NS	NS	NS	NS	-	NS
	NO_2+NO_3	3.47**	NS	NS	NS	-	NS
	Total P	NS	NS	NS	NS	-2.73*	-2.28*
	Conductivity	3.27**	NS	NS	NS	-	NS
	Turbidity	NS	NS	NS	NS	NS	-2.44*
	Secchi Disk	NS	NS	NS	NS	NS	NS
	Chlorophyll *a*	-	NS	NS	NS	NS	NS

Note: Negative "t" value indicates wet mean > dry mean (expected result for all parameters except secchi disk)

* significant at $P < .05$

** significant at $P < .01$

NS not significant

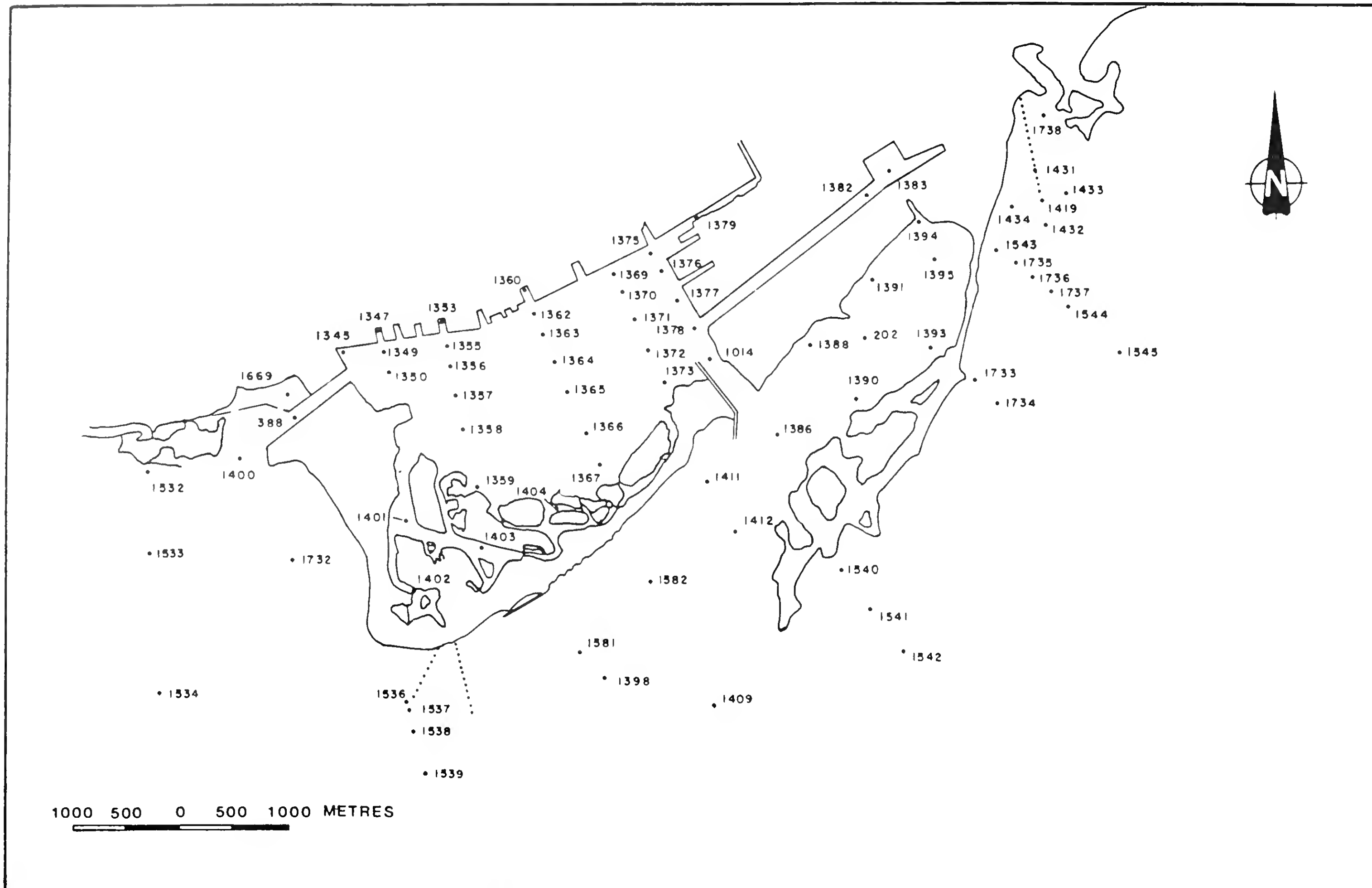

FIGURE 1 : SAMPLING STATIONS USED IN 1976-1978 TORONTO HARBOUR SURVEY CRUISES

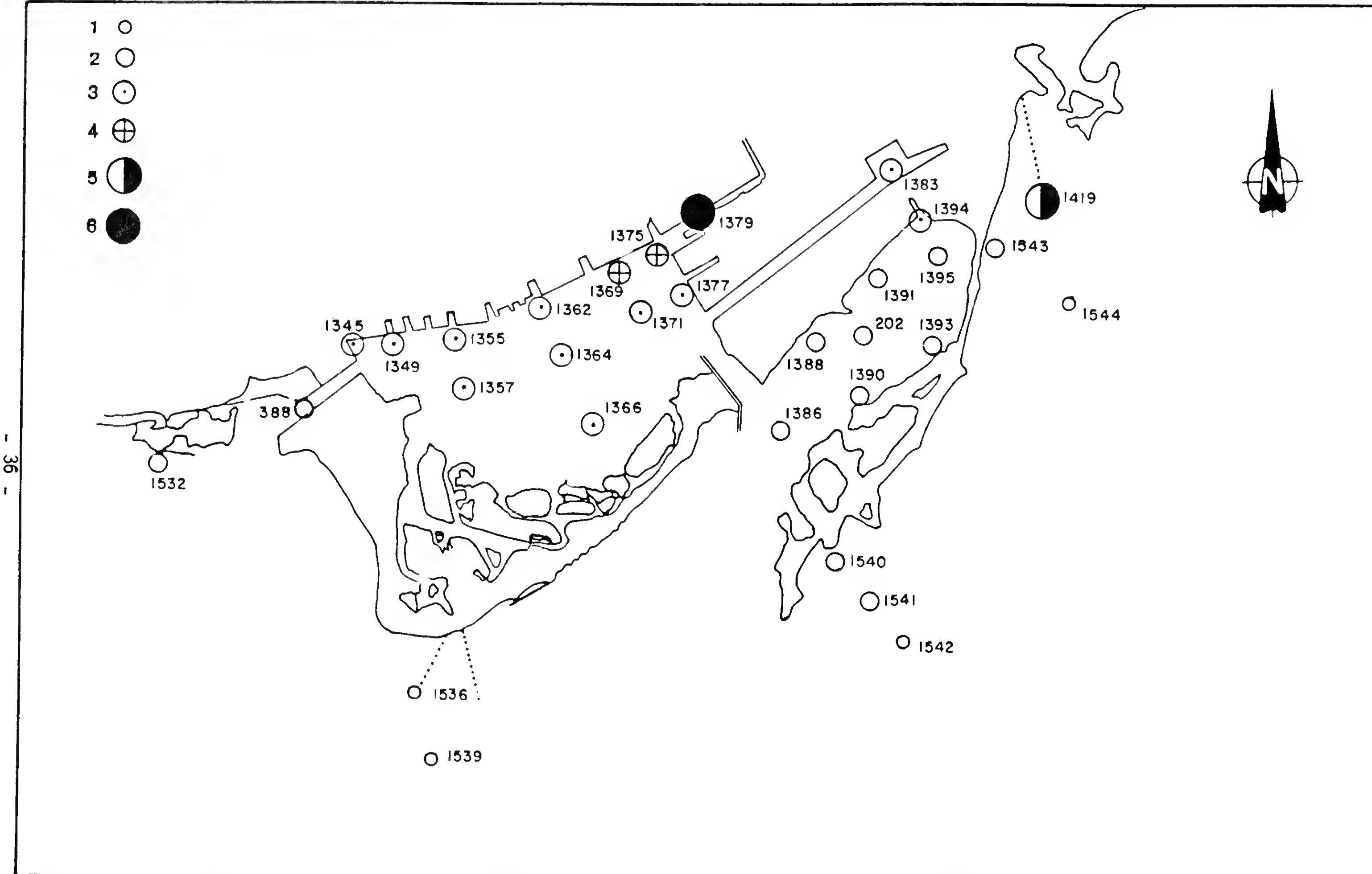

FIGURE 2 : TORONTO HARBOUR ZONATION BASED UPON CLUSTER ANALYSIS OF PRINCIPAL COMPONENTS DERIVED FROM 1977–1978 DRY WEATHER CRUISE MEANS OF NH_3, TKN, $(NO_2 + NO_3)$ – N, TOTAL P, FRP,SI, CONDUCTIVITY, TURBIDITY, SUSPENDED SOLIDS, SECCHI DISC AND TEMPERATURE

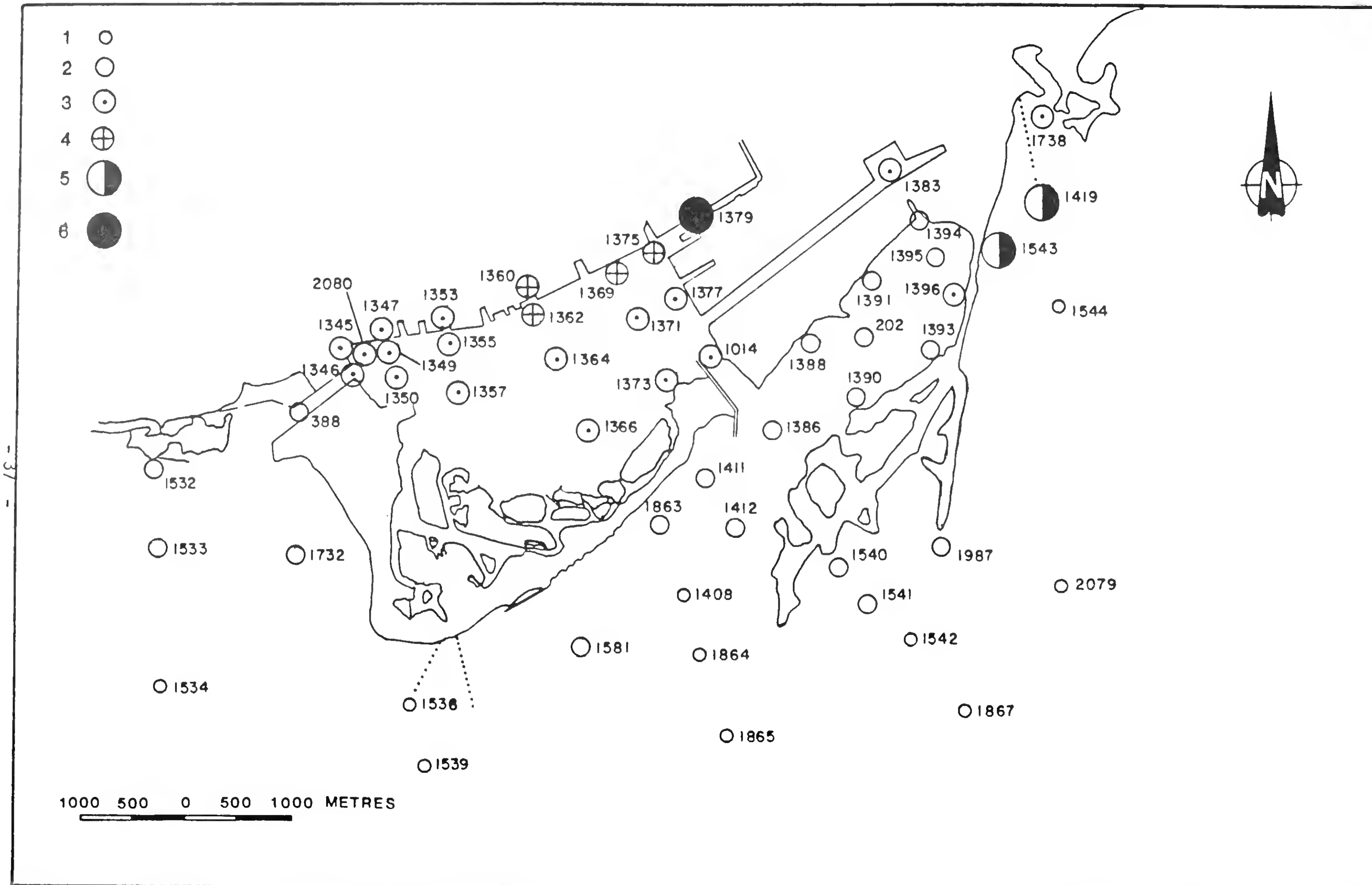

FIGURE 3 : TORONTO HARBOUR ZONATION BASED UPON CLUSTER ANALYSIS OF 1983 DATA FOR TKN, TOTAL P, CONDUCTIVITY, TURBIDITY, SUSPENDED SOLIDS, SECCI DISK AND CHLOROPHYLL a.

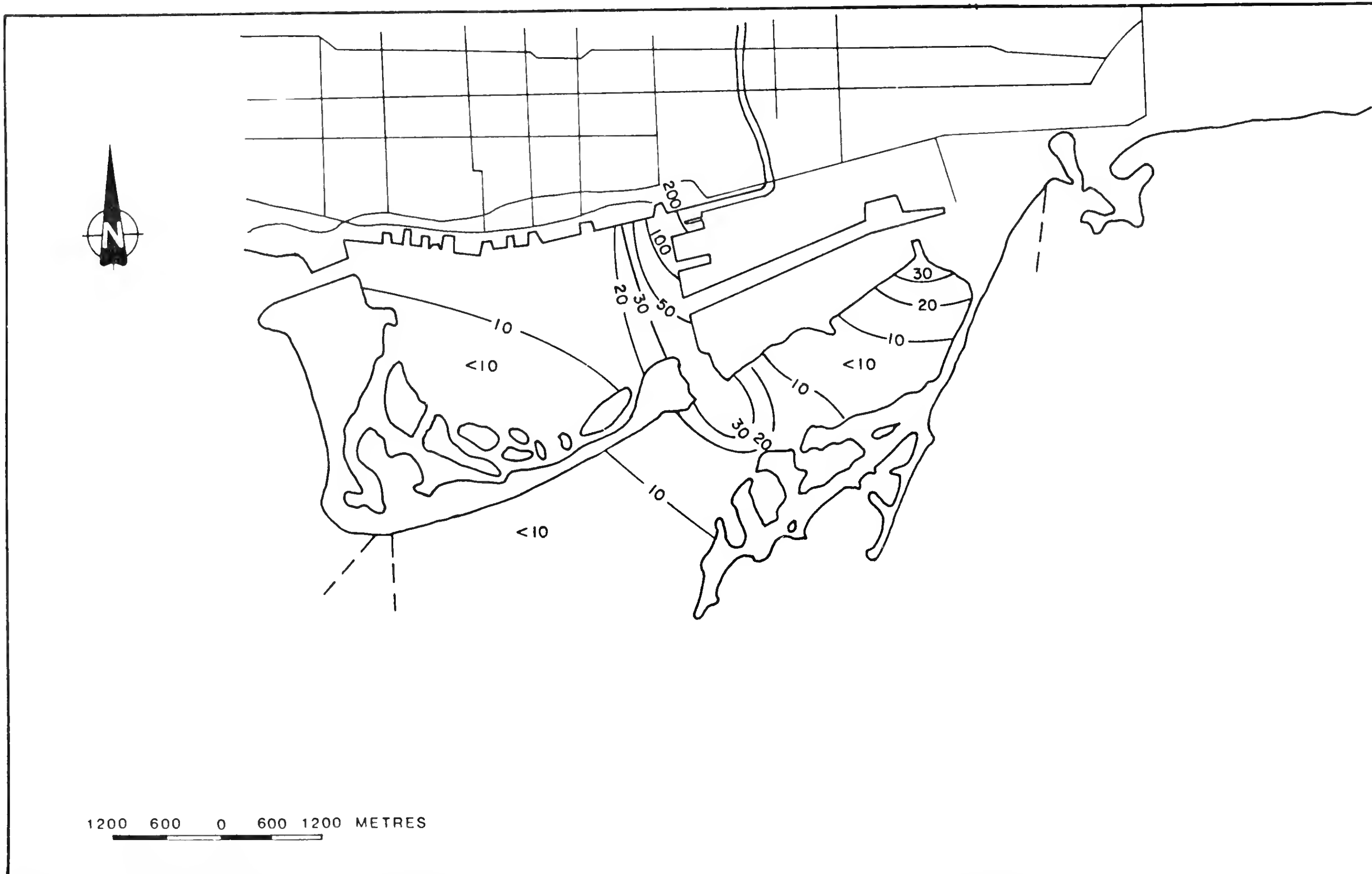

FIGURE 4 : SPATIAL VARIATIONS OF TURBIDITY OBSERVED UNDER RUNOFF CONDITIONS, NOVEMBER 8, 1977

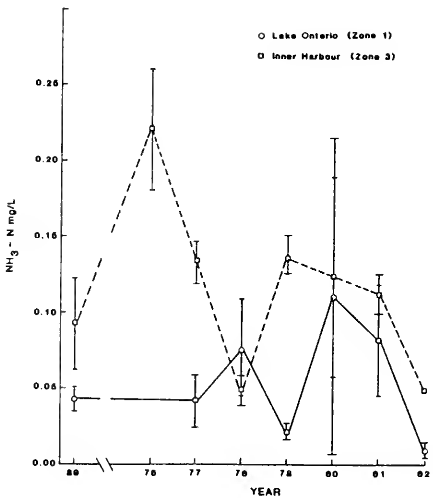

Figure 5a: Year-to-Year Trend of Ammonia-N, Toronto Waterfront.

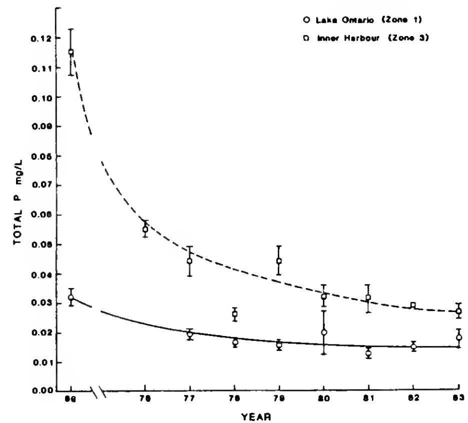

Figure 5b: Year-to-Year Trend of Total Phosphorus, Toronto Waterfront.

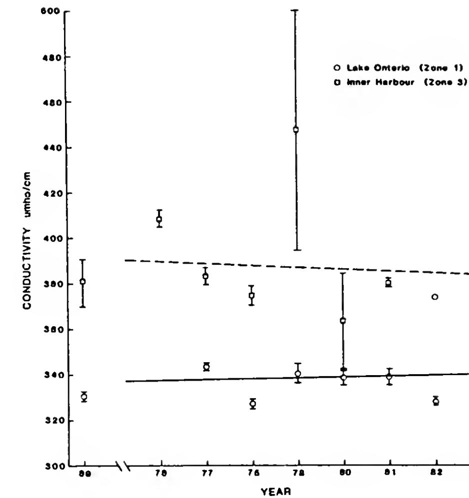

Figure 5c: Year-to-Year Trend of Conductivity, Toronto Waterfront.

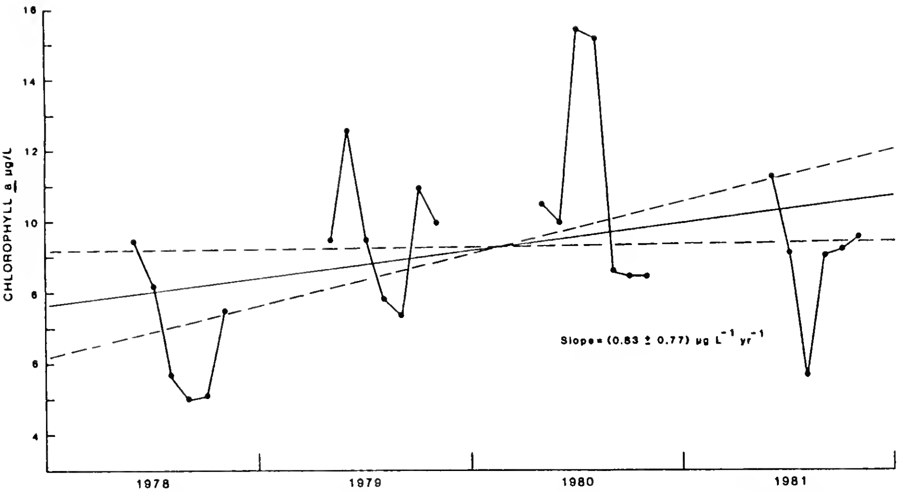

Figure 6a : Year- to -Year Trends of Chlorophyll a at Station 1384 Based on Monthly Means of Daily Survey Results

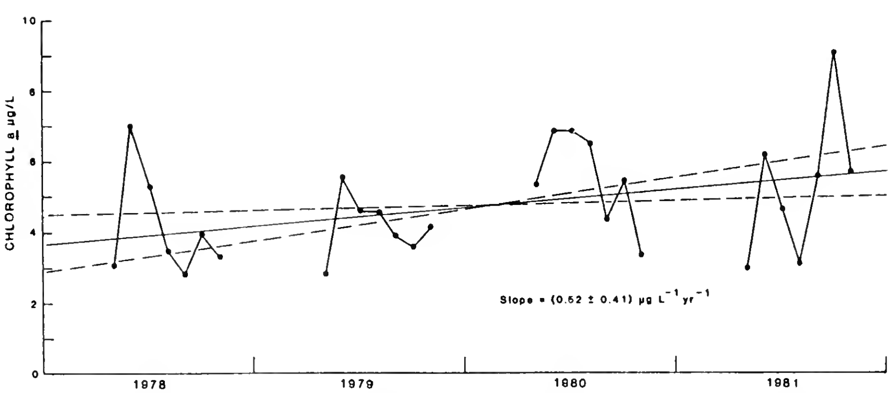

Figure 6b: Year- to -Year Trends of Chlorophyll a at Station 1538 Based on Monthly Means of Daily Survey Results

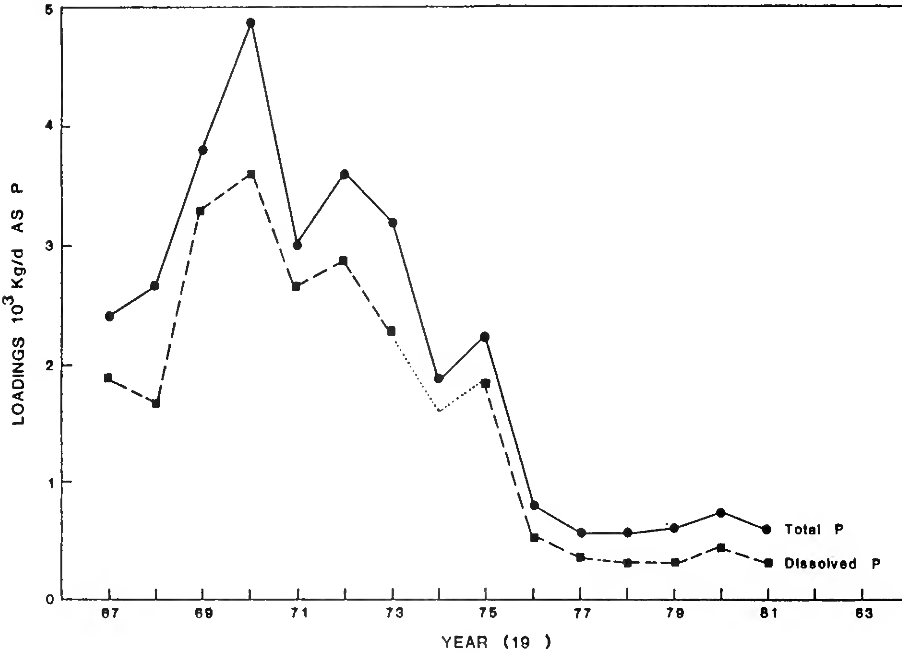

Figure 7a : Annual Average Total and Dissolved Phosphorus Loadings From Main STP, 1967-1981

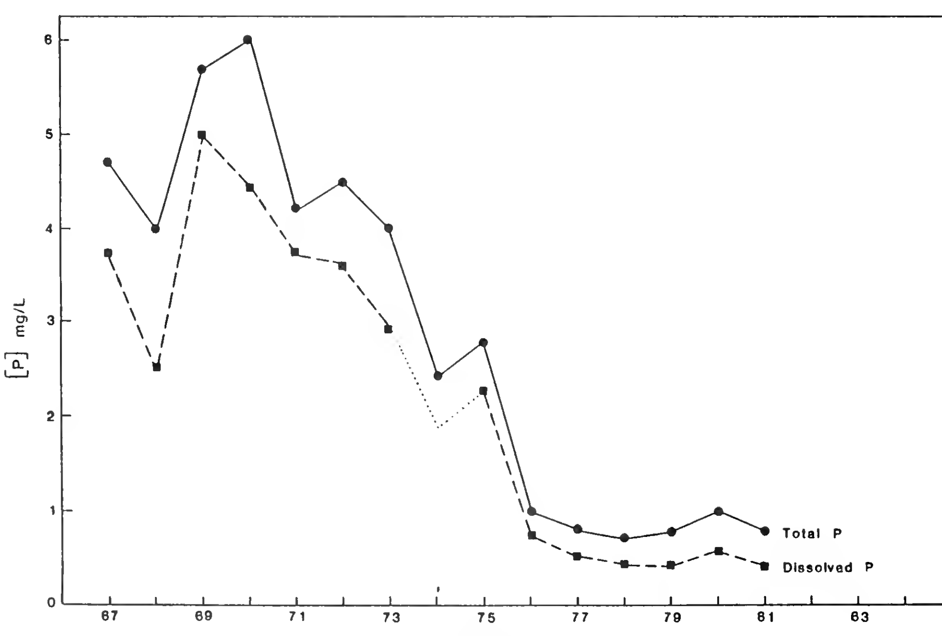

Figure 7b : Annual Average Total and Dissolved Phosphorus Effluent Concentrations, Main STP, 1967-1981.

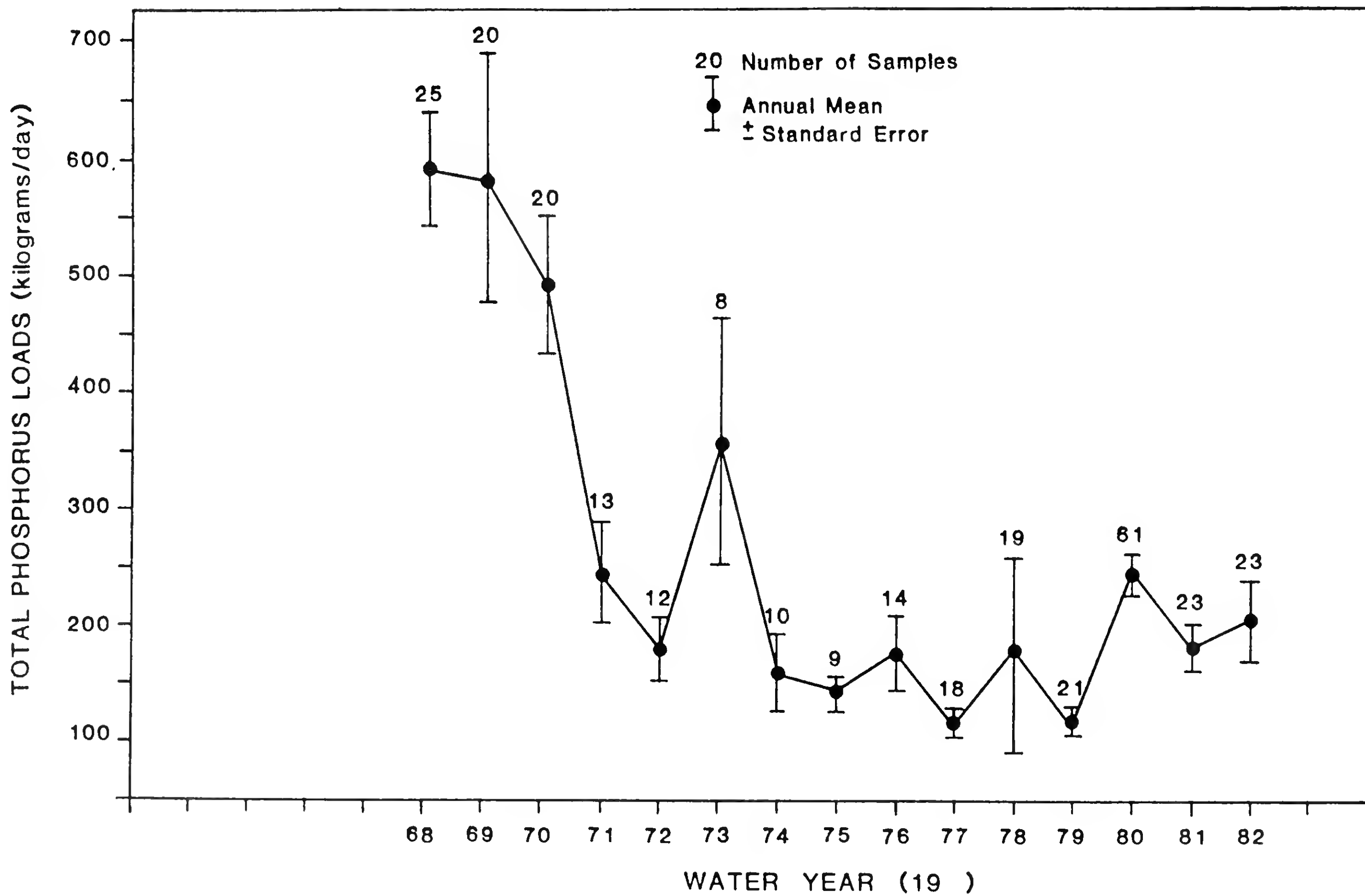

Figure 8 : Improving Trend in Annual Total Phosphorus Loadings in the Don, Water Years 1968-1982.

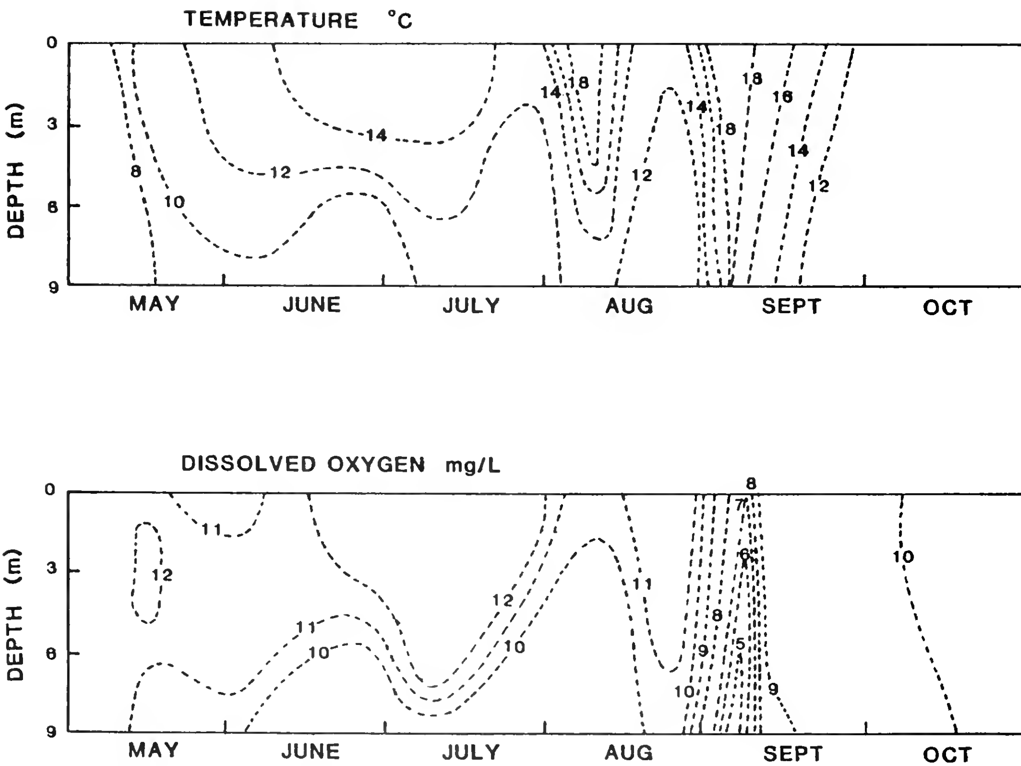

FIGURE 9 : DEPTH/TIME DISTRIBUTION OF TEMPERATURE AND DISSOLVED OXYGEN AT STATION 1364, 1977.

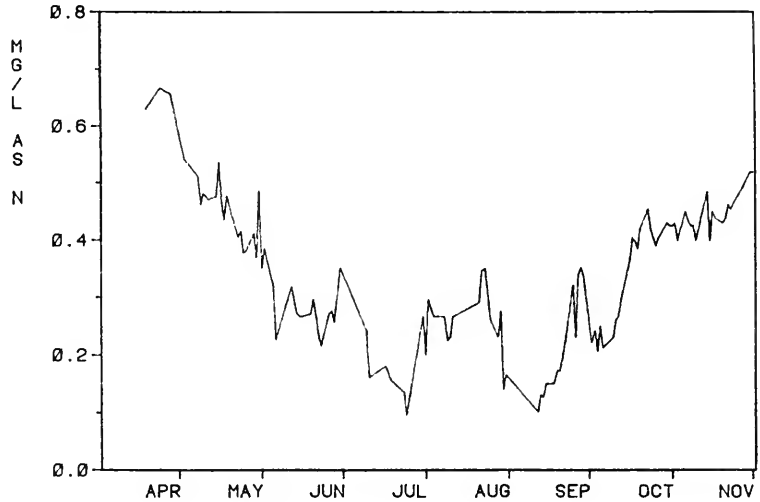

FIG. 10a. PLOT OF (NO2+NO3)-N VS. SAMPLING DATE
TORONTO HARBOUR, STATION 1364, 1979

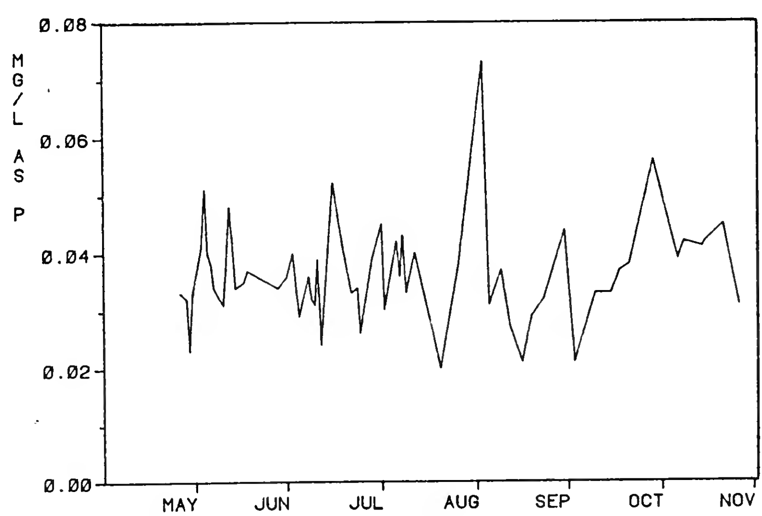

FIG. 10b. PLOT OF TOTAL P VS. DATE
TORONTO INNER HARBOUR, STATION 1364, 1980

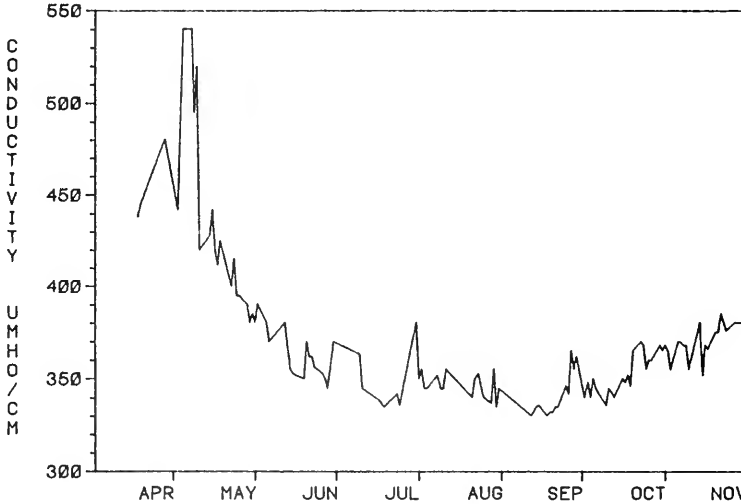

FIG. 11. PLOT OF CONDUCTIVITY VS. DATE
TORONTO INNER HARBOUR, STATION 1364, 1979

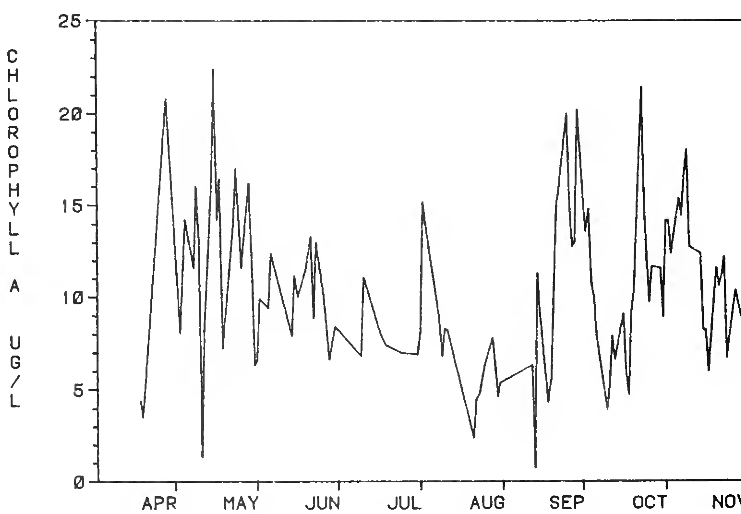

FIG. 12. PLOT OF CHLOROPHYLL A VS. SAMPLING DATE
TORONTO INNER HARBOUR, STATION 1364, 1979

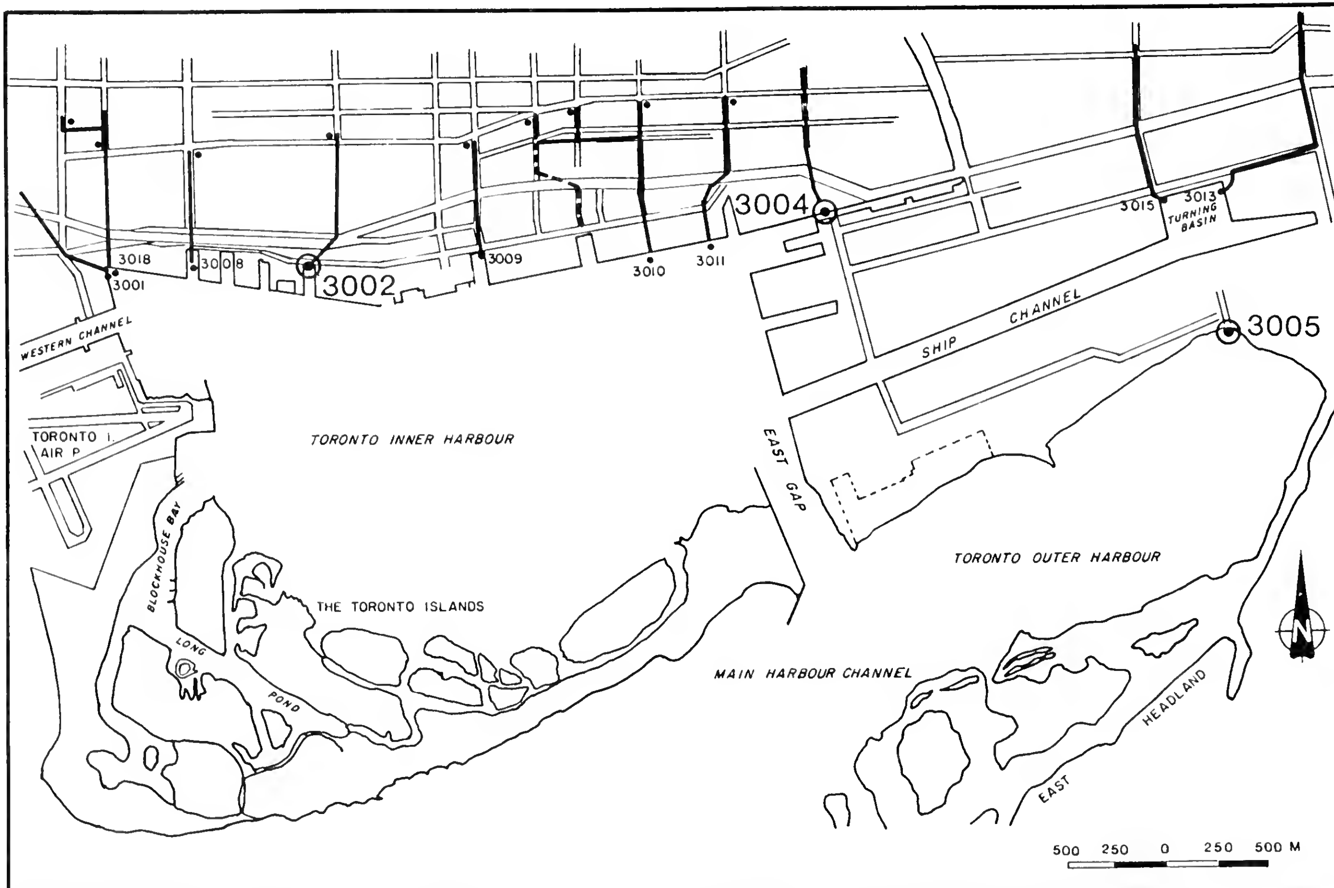

FIGURE 13: LOCATION OF JOINT TORONTO CITY WORKS - MINISTRY OF THE ENVIRONMENT NUTRIENT AND CONDUCTIVITY MONITORING POINTS IN HARBOUR AREA, 1980.

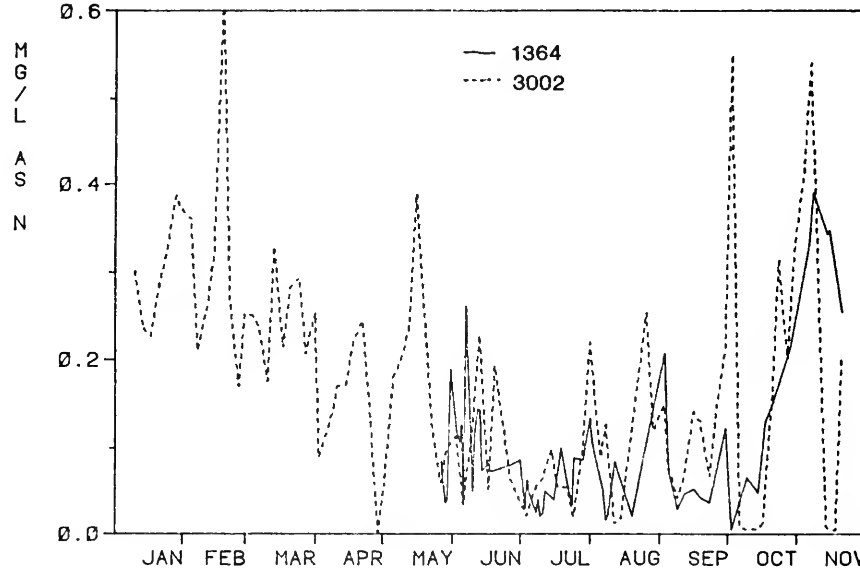

FIG. 14a. AMMONIA-N AT SIMCOE ST. SLIP (3002) AND CENTRAL INNER HARBOUR (1364), 1980

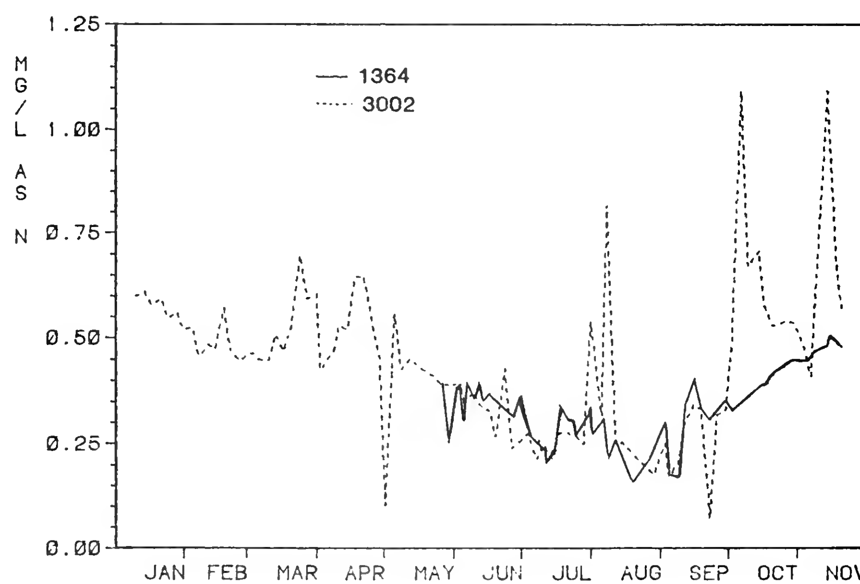

FIG. 14b. (NITRATE + NITRITE) -N AT SIMCOE ST. SLIP (3002) AND CENTRAL INNER HARBOUR (1364), 1980

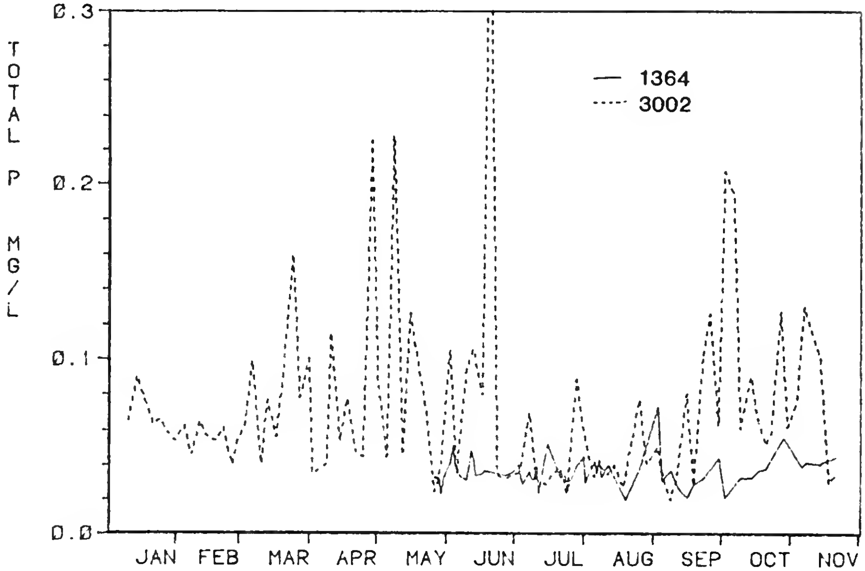

FIG. 14c. TOTAL PHOSPHORUS AT SIMCOE ST. SLIP (3002) AND
CENTRAL INNER HARBOUR (1364), 1980

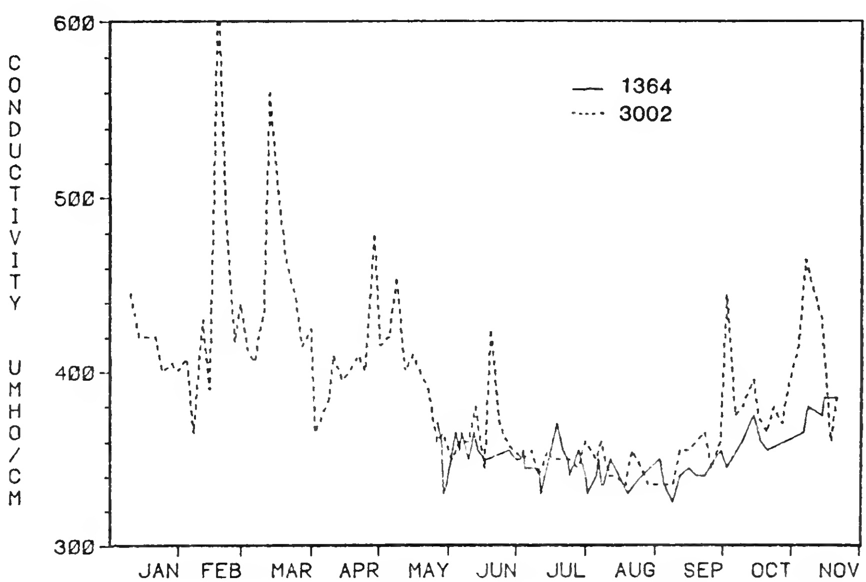

FIG. 14d. CONDUCTIVITY AT SIMCOE ST. SLIP (3002) AND
CENTRAL INNER HARBOUR (1364), 1980

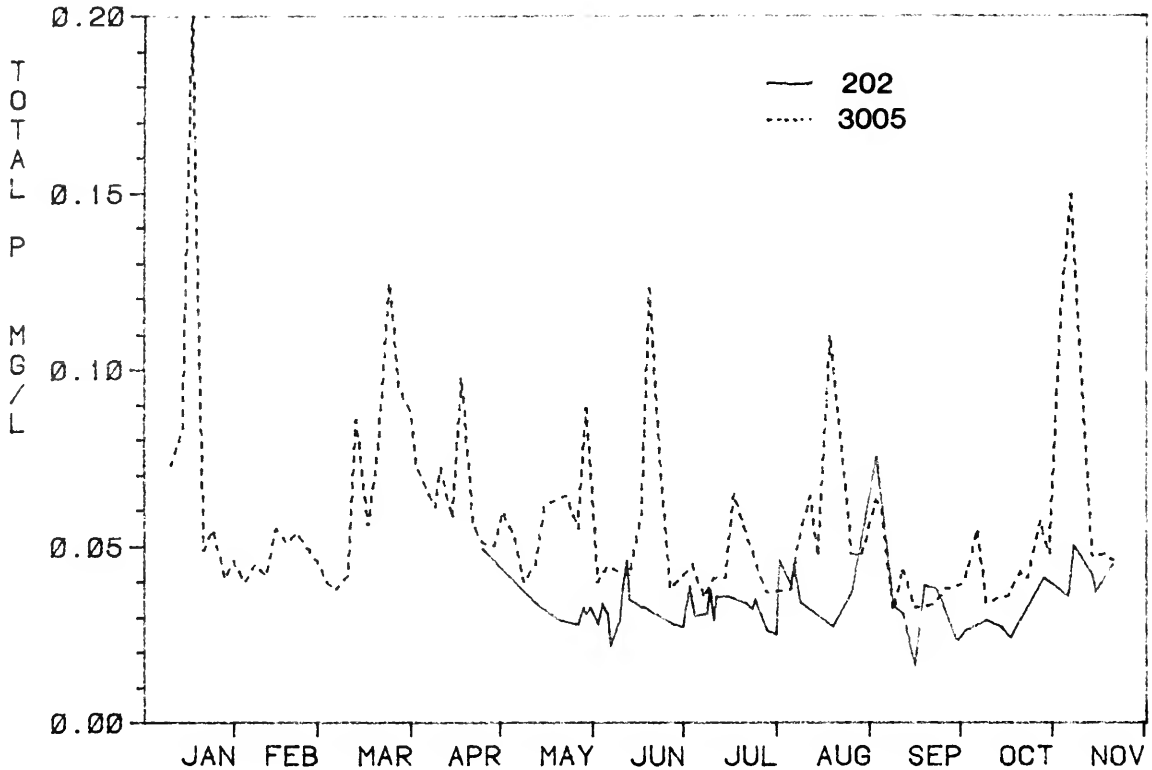

FIG. **15**. TOTAL PHOSPHORUS NEAR HEARN DISCHARGE (3ØØ5) AND CENTRAL OUTER HARBOUR (2Ø2), 198Ø

APPENDIX A.1

APPENDIX A.1

DETAILS OF WATER QUALITY CHANGES DURING RUNOFF PERIODS, 1976-78

Details of rainfall, Don River runoff and overflows from the combined sewers (CSOs) are sumarized for the time intervals immediately before and during each cruise in Table A.1. From these figures, a summary of total rainfall, Don River and CSO runoff data was extracted for each runoff cruise from 24 hours before the cruise until the end of the cruise (Table A.2). The 24h cutoff period was selected as numerical model predictions (Poulton 1980) showed rapid dissipation of CSO dissolved solids within a few hours after cessation of runoff. Although these predictions were only qualitative and do not include parameters such as turbidity and suspended solids, they do indicate the rapidity of advective removal of inputs of contaminants following a runoff.

Impact of runoffs is discussed for each cruise in turn, using dry weather data (Tables 2-3) as a comparison baseline, plus daily survey data (discussed in detail in a separate part of this report) to separate seasonal influences from the runoff effects. Data from the automatic recording water quality monitors located at the East and West Gaps and Keating Channel are also introduced where appropriate.

(a) Cruise 1, 1976, March 31 to April 3

Peak rainfall occurred on March 31, with 27mm recorded at the island, plus 30 x 10^3 m^3 of CSO overflows discharging into the Inner Harbour. Don River flow was spread over March 31 and April 1, with average flow of 15 m^3/s on both days and peak flow of 32.6 m^3/s at 1800 and 1900 hours in March 31. This was one of the largest rainfall/runoff combinations observed during a cruise and had some of the strongest effects on water chemistry. In addition, a larger number of stations was sampled in the Inner and Outer Harbour (intensive survey), thus enabling more detailed definition of water quality zones.

Cruise mean water chemistry data are given in Table A.3 (involving only those stations sampled every cruise, as in Table 2). Compared to dry weather data, significant elevation of nitrate-N, total P, Si, conductivity, turbidity and chlorphyll are found. This is most pronounced for turbidity (250% increase, with accompanying decrease in secchi disk depth).

Zonation maps for several parameters prepared by the method of El-Shaarawi and Kwiatkowski (1977) are shown in Figures A.1(a-e). Evident in those maps is a strong tendency towards extremely elevated concentrations very close to the waterfront mainland, primarily at stations not routinely sampled.

Maximum total P concentrations were obtained on March 31 in each case (the day with maximum CSO discharge), with values of 0.305, 0.425 and 0.335 mg/L being observed at stations 1353, 1360 and 1379 respectively. These are at the Simcoe, and Yonge St. CSO discharges and the Keating Channel outlet, respectively, with the latter also being the site of the Cherry St. runoff. Despite its proximity to the Bathurst and Wellington St. CSOs, station 1345 total P was lower at 0.128 mg/L, perhaps due to mixing with West Gap water. Filtered reactive P was high (as high as 0.215 mg/L at station 1360 on March 31) along almost the entire waterfront, with maximum values again generally on March 31 at the slip stations. Stations not adjacent to slips had less between-day variations in total P and FRP.

Highest conductivity values were found in the northeast portion of the harbour, but values remained elevated across the entire Inner and Outer Harbours except the far west end of the Inner Harbour. No systematic day-to-day variations occurred during the cruise. Runoff of road salt probably accounts for at least part of the general increase. Silicate presented a similar pattern to conductivity in the Inner Harbour, but had significantly lower concentrations in the Outer Harbour.

As already stated, and as expected, the most pronounced effect of the runoff was observed with turbidity, plus the concomitant drop in secchi disk depth. Turbidity was higher than the dry weather average by factors of 1.8, 3.1, 2.5 and 3.7 in zones 2,3,4 and 6, respectively, with the largest factor at the Keating Channel and the smallest one in the lake. Maximum turbidity at the Keating Channel was 50 FTU on April 1. Variations across the harbour were not large during this cruise, with the effect of the Keating Channel appearing only at station 1376 in the northeast part of the harbour. No evidence of high turbidity in stormwater runoff inputs was found.

The Outer Harbour was influenced almost as strongly as the Inner Harbour during this runoff, with elevated turbidity, conductivity, nitrate and total P values at many stations approaching those of the Inner Harbour. This presumably indicates inputs through the East Gap and the Hearn cooling water flow, as well as possible erosion of solid material from shoreline areas.

(b) Cruise 2, 1976, May 4-6

Rainfall and runoff occurred only on the last day of this cruise, and appeared to have been too late to have a pronounced effect on water quality, as no significant day-to-day variations are evident in the data. Minor elevations in nutrients and conductivity may have been due to seasonal or irregular changes (see discussion of daily data) and are probably not important. The same may be true of turbidity, although high winds (24-30 km h^{-1}) may have increased resuspension of bottom material to produce the observed increase. It should be noted that no significant between-zone differences in turbidity existed during this cruise.

(c) Cruise 4, 1976, July 5-9

Rainfall and runoff occurred only during the late hours of July 7 and early hours of July 8, with peak Don River flow of 13.9 m^3/s at 2100 h on July 7. Stormwater runoff was relatively minor. Most of the runoff occurred at the Bathurst and Wellington CSOs at the

northwest corner of the harbour, and resulted in sharply elevated concentrations in nearly all water quality parameters in a sample taken at station 1345 at 0915 on July 8, compared to samples taken July 6 and 9. As this was an intensive survey cruise, data are available at a larger number of stations, including slip locatons 1347, 1353 and 1360. The first two of these showed a far smaller increase in pollutant concentrations on July 8 and the last showed maximum values on July 6. Among these three locations, runoff was only reported at the Simcoe St. CSO (1353) during this period. Therefore, qualitative agreement between runoff volumes and water quality data exists for at least three of these locations.

Other parts of the harbour did not show effects of this small runoff, except perhaps for total P which was slightly higher on July 8 but still within the normal range of fluctuations for this parameter (see daily survey data). Indeed, much of the eastern part of the harbour showed highest values for most parameters on July 6, except at the Keating Channel (1379) where the peak was on July 9. High values on July 6 may be residuals of a Don River runoff which peaked at 19.6 m^3/s at 1700 h on July 3 and only declined very slowly, still being slightly above baseflow on July 5. No influence of this minor runoff was found in this part of the harbour, nor was anything observed outside the Inner Harbour.

(d) <u>Cruise 3, 1977, June 27-29</u>

Rain in the Don River watershed late on June 28 produced an impact on the Todmordon gauge only after midnight, with peak flow of 49 m^3/s observed at 0500 h on June 29. This produced a "first-flush" effect on most water quality parameters at station 1379 on June 29. Parameters reflecting dissolved components were at their minimum on June 29, while turbidity and suspended solids peaked at 210 FTU and 175 mg/L, respectively. Total P also peaked at 0.49 mg/L on June 29, reflecting the P content of the suspended material. Maximum conductivity at the Keating Channel robot monitor was 946 umho/cm at 0340 h on June 29, after which the conductivity

dropped rapidly to values below 400 umho/cm 2 h later. Some of the runoff was transported southward along the east wall of the harbour, producing a peak conductivity at the East Gap robot monitor of 405 umho/cm at 0820 h and turbidity values of 15 to 20 FTU between 1820 h and 2120 h on the same day.

Most of the high turbidity load was transported westward along the north shore of the Inner Harbour, producing very distinct turbidity gradients (Figure A.2). Turbidity values of 20 to 130 FTU in this area contrasted sharply with values between 1 and 3 FTU in the southern and western parts of the Inner Harbour and the entire Outer Harbour.

Dissolved nutrients and conductivity on June 29 showed a similar pattern to that illustrated for turbidity. Values in the northeast part of the harbour (zone 4; stations 1369 and 1375) were high for the entire cruise. This may have been a residual effect from substantial runoffs, which occurred on June 25 and may not have been removed from the area because winds were light and variable. Because of this factor, numerical model predictions of pollutant dispersion were not applicable to this time period.

No effect of this runoff was visible in areas outside the Inner Harbour.

(e) Cruise 4, 1977, September 1-3

Maximum rainfall and runoff occurred in the first day of the cruise, with the largest one-day total CSO overflows of any cruise period (57×10^3 m^3) being observed. Average Don River flow was 14 m^3/s with maximum flow of 50.7 m^3/s occurring at 1900 h. This runoff began abruptly at 1300 h, at which time Don River flow increased from baseflow to 31.1 m^3/s. Samples were collected during the morning of September 1 and represented dry weather data.

The impact of runoff was noticed on September 2, with an unusual turbidity distribution (Figure A.3) being observed. While most of the northern and western parts of the Inner Harbour showed turbidities above 10 FTU, the turbidity at stations 1371, 1375 and 1377 (eastern part of Inner Harbour) was below 2 FTU and similar to Outer Harbour values. Apparently, a strong inflow through the East Gap had occurred. No current meter data are available to verify this, however.

Most other chemical parameters showed a similar spatial distribution to turbidity, with a strong effect of runoff on September 2 producing elevated concentrations of all Inner Harbour locations except the three already noted. Although the high CSO overflows no doubt had a strong impact on the harbour, the Don River flow volume was more than 20 times the total CSO runoff volume on September 1, and no doubt caused the largest proportion of the elevation in concentrations observed on September 2. No quantitative statement can be made due to the lack of concentration measurements at the input points.

(f) Cruise 5, 1977, November 7-10

Peak runoff volumes occurred on the evening of November 7, with the heaviest island rainfall (57mm) of any cruise, CSO runoffs of 24 x 10^3 m^3, an average Don River flow of 34.3 m^3/s and maximum Don River flow of 113.6 m^3/s at 2200 h. Although runoff began in early afternoon, this was probably too late to have an effect on the November 7 samples. This cruise was concluded on November 9 on all stations except 1419 and 1540, hence the minor runoff on November 10 is ignored.

Again, a highly pronounced effect of runoff on turbidity is noticed. Relatively uniform turbidity of 3 to 4 FTU on November 7 gave way to the pattern shown in Figure A.4 for November 8, showing elevated turbidity in both Inner and Outer Harbours. Most of the turbidity is transported southward along the eastern edge of the Inner Harbour, through the East Gap to the Outer Harbour. Turbidity

is also being drawn through the Hearn G.S., entering the Outer Harbour at the northeast corner. Within the Inner Harbour, the result agreed qualitatively with numerical model predictions of southward transport under east wind conditions (see appendix; Poulton 1977b, 1980). The strong transport through the East Gap is not predicted; however, this is a function of the open boundary current meter data used as model input.

On November 9, elevated turbidity levels were still evident (Figure A.5) with values similar to November 8 except near the Keating Channel, East Gap and Hearn outfall. Other areas have more uniform, elevated turbidity. This is a probable consequence of slowly decreasing suspended matter input from the Don River and CSOs, and cannot really be compared with model predictions, since conductivity (used in the model) decreases far more rapidly with time than turbidity, as the runoff progresses.

An impact of nutrients from stormwater runoffs (generally NH_3 and total P) is noticed in the data taken November 8-9 at most other Inner Harbour locations. Except for station 1366 in the far southern part of the harbour, the average of all other zone 3 stations was .061, .120 and .107 mg/L for ammonia, and .031, .059 and .046 mg/L for total P on the three survey dates, respectively. The three dates represent pre-runoff, maximum impact, and a continuing impact 24 h later (as observed with turbidity above).

(g) Cruise 2, 1978, September 29-October 3

Rainfall and runoff occurred during the night of September 30-October 1, with hourly peak Don River flow of 43.8 m^3/s at 2100 h on September 30. Average Don River flows were 8.4 and 6.4 m^3/s on the two days, and the two-day total CSO overflow was 29 x 10^3 m^3. Samples were taken at most stations on September 29 (before runoff), October 1 (effect of runoff still present), and October 2-3. The automatic water chemistry monitors were also operating at both Gaps and the Keating Channel throughout the cruise period.

Turbidity and suspended solids showed a maximum of 40 FTU and 48 mg/L respectively at station 1379 in October 1. On October 2, values of 17 FTU and 17 mg/L indicated that the river was still carrying considerable sediment despite the fact that flows were only slightly above baseflow. The chemistry monitor at the Keating Channel indicated that a brief peak of conductivity (maximum 989 umho/cm) coincided with the river flow peak at 2040 h on September 30. Values of 300 to 500 umho/cm were recorded 2 to 10 hours before, and 2 to 24 hours after this peak. All nutrient parameters also peaked at station 1379 on October 1, but were only slightly reduced in concentration October 2 before dropping to values approximating dry conditions on October 3.

Samples were obtained from several harbour slips (1347, 1353, 1360) during this cruise. However, effects of the runoff at these locations and 1345 were ambiguous, with peak nutrient concentrations frequently being observed on October 2, one day later than expected. A small increase in turbidity occurred on both October 1 and 2. The western and central parts of the harbour showed similar delayed responses, with increased nutrient (chiefly ammonia and total P), turbidity and suspended solid concentrations on October 2 and 3, compared to the first two days of the survey. Possibly related to this fact, the automatic chemistry monitor at the East Gap showed alternating periods of high (10-20 FTU) and lower turbidity during the entire time interval October 1-3. These turbidities were higher than harbour values (about 4 FTU) and may have been due to proximity (2m) of the monitor intake to the channel wall, or to the different nature of the turbidity system and calibration, compared to grab samples. Only one small increase in conductivity, on October 1, was observed.

Most Outer Harbour stations show increased values of ammonia and turbidity on October 3, again a delayed response but apparently reasonable considering the presence of high-turbidity water at the chemistry monitor.

During the cruise, extremely high but variable ammonia concentrations were found at the Main STP outfall (station 1419) (up to 9 mg/L). Although some increases in ammonia were detected along the headland as far south as stations 1733-1734, the main plume of the STP was directed northward into Ashbridges Bay, where ammonia, total P and FRP peaked at 3.05, 0.305 and 0.220 mg/L on October 1. No effects of the runoff were found in other areas of the lake.

These relationships were summarized in a cluster analysis of the data from that cruise alone (Figure A.6). This showed the Inner and Outer Harbours to be indistinguishable, as runoff effects were felt throughout, though not always on the same day. Likewise, the two lake zones defined by dry weather data were not distinguished, but a zone defining the approximate bounds of the Main STP plume was observed.

APPENDIX A.2

APPENDIX A.2

AUTOMATIC WATER CHEMISTRY MONITORS, 1977-78

The operation of digitally recording water chemistry monitors already described for 1975-76 (Poulton 1977a) was resumed for June-September 1977 and September-October 1978, an interval which included several of the survey cruises. These monitors provide a continuous (20-minute recording interval) record of temperature, dissolved oxygen, turbidity, pH and conductivity including their diurnal and seasonal variations as well as variations with meteorological conditions and extreme values which could be missed during manual sampling. The data records provided are also suitable for direct entry into the time-dependent 2-dimensional numerical model of currents and water quality (Poulton 1977b, 1980).

As in the 1975 and 1976 surveys, three shore-mounted Schneider robot monitors were used, one at each Gap and one at the Keating Channel. These monitors were housed in enclosed shelters and water was pumped to them from the mid-depth of each channel using either a submersible pump or a shore-mounted suction pump. No operations of submerged water quality monitors in the harbour or ship areas were attempted in this time interval.

The installations and data analysis methods were identical to those described previously (Poulton 1977). Summary statistics for all time intervals with valid calibration are given in Tables A.4 (1977) and A.5 (1978). As in 1975-76, the two Gap locations were characterized by low coefficients of variation during nearly all operating intervals. The West Gap data were especially constant, with results generally characteristic of lake water. This is expected considering that the predominant water flow is from lake to harbour at this location (Kohli 1978). Water temperatures were slightly more variable; periods of low temperature coincided well with intervals of upwelling along the north shore of Lake Ontario as indicated by temperature data obtained by Ontario Hydro at several generating stations (Ontario Hydro unpublished data).

Dissolved oxygen was nearly always close to saturation at both Gaps. The lowest dissolved oxygen at the East Gap was approximately 69% saturation, which occurred on the night of August 14-15, 1977 under runoff conditions (August 14, Don River average flow = $11.8 m^3/s$), and was accompanied by increased turbidity and conductivity values. At the West Gap, dissolved oxygen averaged 85% saturation in 1978, similar to the 90% level found in 1975 but lower than the 1976 and 1977 averages. The 1975 and 1978 data represent autumn months, while 1976 and 1977 data were collected during the summer. Except for possible mixing of relatively lower - D.O. water from the hypolmnion, no reason can be seen for the reduced autumn D.O. values.

Turbidity values are higher than those obtained during survey cruises. The only possible reason for this is different methods of measurement and calibration, compared to methods used in the laboratory. Results are more constant at the West Gap, with occasional increases at the East Gap related to runoff events, as discussed elsewhere.

As observed in 1975 (Poulton 1977a), conductivity values at the East Gap are consistently slightly higher than those at the West Gap. This is in agreement with the general flow regime (inflow through the West Gap and outflow through the East Gap). Also as indicated previously (see cruise data), increases in conductivity at the East Gap are frequently related to events of high conductivity and runoff observed at the Keating Channel.

Again, as seen in previous years, the Don River water quality observed at the Keating Channel is extremely variable, especially with respect to conductivity, which during runoff usually displays a "first flush" effect, reaching a maximum value early in the runoff, followed by a rapid decrease to a minimum (occasionally even below normal lake conditions) at or shortly after maximum streamflow. Figure A.7 (Poulton 1980) illustrates a typical episode.

Overall, the automatic water chemistry monitors did not produce any significantly new information compared to their previous operation. No further operations were conducted in 1979-83. Although this equipment did prove highly useful in defining the periodicities of lake-harbour exchange flow in Hamilton (Palmer and Poulton 1976), the equipment is expensive and out of date. Despite the fact the monitors may be useful in defining changes in water quality as a result of such actions as the closing of the Hearn generating station, no plans presently exist to acquire updated equipment.

Table A.1

SUMMARY OF ENVIRONMENTAL CONDITIONS
TORONTO HARBOUR CRUISES 1976-1978

CRUISE	DON RIVER FLOW (m^3sec^{-1})	DON RIVER WATERSHED RAIN (mm)	ISLAND RAIN (mm) & SUN (hrs)	ISLAND WIND MAJOR DIR'N %	ISLAND WIND SPEED (km/hr)	LAKE LEVEL (cm above IGLD 74.0 m) (Inner Harbour Volume change)	TEMPERATURE (°C) LAKE	TEMPERATURE (°C) AIR	SEWER OVERFLOWS (m^3)	HEARN G.S. FLOW (m^3sec^{-1}) (% of Inner Harbour/day)
1-1976 Mar. 31 Apr. 1-3	-major flow 10 days before cruise (27) -base flow for 2 days before. -at start of cruise flow at 15 and decreasing during (peak at 35 on 31st)	-major snowmelt 11 days before cruise. -periodic rain before -19 mm on first day, 2 on second.	rain -periodic before 27 on 31st 2 on 1st .5 on 2nd. sun - .0 1 - 6.2 2 - 6.4 3 - 9.4	east on 31st west on rest east 30% westerly & others calm- 0.2%	 30 km/hr. 15 km/hr.	varying about 115 cm above, (+6.026x10^6m^3 or 16.8% above IGLD vol.)	Mar.22 1°near Toronto Apr. 12 3°C off Toronto.	max 13 mean 7	March 31 Wellington-19444 Simcoe - 4305 Parliament- 5001 Cherry St.- 1142 Apr. 1 Wellington- 816	1.8 x 10^6 (4.3%)
2-1976 May 4-6	-May 4 & 5-base-flow -May 6-rose to 15 at midday; peak 25 -small flush May 2-3 (10) -large flow 9 days previous 16.	May 5 - 3 mm May 6 - 33 mm May 2 - 6mm Apr. 24-14mm 25-22mm	rain May 6 - 13 mm May 2 - 6 mm Apr. 24- 6 25- 34 sun 3-6.5 4-9.0 5-6.1 6-0	May 2-5 S&W May 6 N&E W 27% SW 18% calm 5%	 30 km/hr. 24	varying about 135 cm above (7.07x10^6m^3 above or 19.7%)	-	max 22 mean 15	May 2 Wellington- 1853 Simcoe - 220 Parliament- 723 Cherry - 35 May 6 Wellington- 20245 Bathurst - 110 Simcoe - 5056 Parliament- 15161 Cherry - 94	2 x 10^6 (4.6%)
3-1976 June 29-30 NOT ASSESSED DATA INADEQUATE	June 29 - base to 45 late in day. June 30 a.m. - down to 10, peak of 28 then down again	on and off for two weeks before June 29 - 25 mm June 30 - 11 mm	rain June 30 - 11 sun June 29 - 6.3 30 - 0.2	E 15% E 12% W 9% calm 4%	21 13 10	varying about 135 cm above (7.07x10^6m^3 or 19.7% above)	June 17 8-10°C	max 25 mean 20	June 25 Leslie S - 79 June 26 Leslie S - 124 June 28 Wellington- 1725 Simcoe - 95 Parliament- 1998 Cherry - 82 Leslie N - 897 June 30 Wellington- 7951 Bathurst - 11 Simcoe - 1070 Parliament- 4923 Cherry - 586	Not calculated.
4-1976 July 5-9	July 5 & 6 - 4 and drain to 3 July 7-2 late p.m. peak 14 July 8 decrease from 10 to 3 July 9-2	rain June 28-July 3 25 mm on 29 5-10 mm on others July 7-7 mm July 9-3 mm	rain July 8 - 13 mm on and off June 23-July 3 sun 5 - 10.7 6 - 11.4	N 13% W 17% WSW 10% SW 10% calm 8%	14 8 8 11	varying about 135 cm above (7.07x10^6m^3 or 19.7% above)	July 13 4.6-6°C (up-welling) July 14 6°C	max. 30 mean 24	July 3 Wellington- 623 Parliament- 748 Cherry - 63 July 7 Wellington- 7589 Bathurst - 48	variable-average 1.2x10^6 (2.8%)

			7 - 0.5 8 - 0.8 9 - 12.7						Simcoe - 1924 Cherry - 859 Leslie - 371 July 8 Wellington- 619 Bathurst - 3 Parliament- 3020 Cherry - 39	
5-1976 Aug.4-6	Aug.2-6 baseflow 2 high flow one week prior 20 average	.3mm Aug.5 July 28-31 10mm with peak of 25mm	rain none during: July 29- 26mm July 31- 22mm sun 4 - 10.3 5 - 3.2 6 - 10.0	N 5% E 5% SE 5% W to SW 34% S to SW 12% calm 0%	16 11 12 12 20 km/hr.	varying about 115 cm above (6.03x10^6m^3 or 16.8% above)	Aug. 16 16^{o}C	max. 26 mean 20	None	1.77x10^6 (4.2%)
6-1976 Nov.3-5	Nov.1-5 baseflow 2	Nov.3-.5mm Oct.30-Nov.3 .5/day but 2mm on 31st	rain Nov.4 - 1 mm Oct.30 - 1.5 mm Oct.31 - 2 mm sun 3 - 6.9 4 - 2.1 5 - 4.3	NW 15% SW 18% WSW 15% W 15% calm 5%	14 19 21 15	varying about 60 cm above (3.1x10^6m^3 or 8.7% above)	Nov.15 4^{o}C	max. 11 mean 5	None	1.7x10^6 (4.3%)
1-1977 May 9-12	May 7-12-baseflow 1.8 average flow peak of 20 16 days before cruise (Apr.23)	no raining during May 1 - 2 mm.	rain 12 - 1mm May 2 - 2 mm sun 9 - 11.4 10 - 10.0 11 - 9.1 12 - 9.4	N 43% W to NW 30% calm 0%	24 25-15	varying about 75 cm above (3.93x10^6m^3 or 10.9% above)	-	max. 24 mean 14	None	2.34 x 10^6 (5.9%)
2-1977 May 28-31	May 28-31 base-flow 1.8 May 24,25 - 5	May 28 - 1 mm May 31 - 8 mm (did not affect flow until after cruise) May 24 - 19 mm	rain May 28 - 2 mm May 31 - 9 mm May 24 - 1 mm sun 26 - 13.5 29 - 12.6 30 - 13.6 31 - 9.5	W to SW 24% E to ESE 49% NW to WNW 11% note: before-W&SW during- E & ESE	12 22-20 9-18	varying about 73 cm above (3.83x10^6m^3 or 10.6% above)	May 26 8-12^{o}C (inshore)	max. 31 mean 18	None	1.94x10^6 (4.9%)
3-1977 June 27-29	June 25 peak of 74 and decreasing June 26-28- base-flow 1.8 June 29 peak of 50 & decrease to 7 in p.m. average flow of 15 on June 18	June 28 - 19mm June 29 - 1 mm June 24 & 25-16&7 also rain June 16-20, 8-13 mm	rain June 29- 24 mm June 25- 19 mm June 17 & 18 - 6 & 22 mm sun 27 - 4.2 28 -11.2 29 - .9	variable N 12% E 8% ESE 11% S 14% SW 12% W 12%	 15 14 15 11 14 23	varying about 68 cm above (3.56x10^6m^3 or 9.9% above)	June 21 6 inshore -8^{o}C	max. 26 mean 20	June 25 Wellington- 14831 Bathurst - 2632 Spadina - 15460 Simcoe - 3125 Church - 1746 Jarvis - 353 Sherbourne- 1970 Parliament- 721 Cherry - 1033 Leslie 5 - 1169	2.34x10^6 (5.9%)

4-1977 Sept.1-3	Aug 30-31-base-flow 1.8 Sept.1 base to 2 (peaks of 32 & 50 in p.m.) Sept.2 - 10 decreasing to 3.5 Sept.3-3.5 decreasing to 1.8 Aug.22 - 7 avg. flow.	Sept.1 - 20 mm Sept.2 - 3 mm Aug.29 - 0.5 mm Aug.21 & 23 - 14 & 7 mm	rain none during: Aug.27 - 1 mm Aug.21 - 11 mm Aug.23 & 24, 0.5 & 3 mm sun 1 - 5.7 2 - .2 3 -11.4	N to NE 30% NW to NNW 13% E 17% ESE 11% S 6% calm 3%	12-14 11 8 12 9	varying about 75 cm above (3.93x10^{6}m^3 or 10.9% above)	Aug 25 30°C	max mean	28 22	Sept. 1 Wellington- 540 Bathurst - 2100 Spadina - 19087 Simcoe - 7751 Yonge - 11227 Jarvis - 7916 Parliament- 1259 Cherry - 2353 Leslie N - 4901 Sept.2 Jarvis - 32	1.9x10^6 (4.8%)
5-1977 Nov.7-10	Nov.5 & 6 -baseflow 1.8 Nov.7-from base increasing to peak of 113 Nov. 8-from peak to 10 Nov.9-6 Nov.10 - 6 increasing to 39 then decreasing. Baseflow 1.8 for 20 days prior to cruise	No rain for 20 days previous to cruise. Nov 6 - 3.5 mm Nov. 7 - 39 mm Nov. 8 - 0.2 mm Nov. 9 - 2 mm Nov.10 - 14 mm	rain No rain-20 days previous Nov. 4 - 1 mm Nov. 7 - 57 mm Nov. 8 - 2 mm Nov. 10- 15 mm sun 7 - 0 8 - 0 9 - .1 10 - 0	ESE to ENE every day except SW-WNW on 10th ENE 15% E 64% ESE 10% calm 0%	 24 30 40	varying about 65 cm above (3.41x10^{6}m^3 or 9.5% above)	Oct.31 9°C	max mean	13 10	Nov. 7 Bathurst - 702 Spadina - 4560 Simcoe - 12826 Sherbourne- 2651 Parliament- 2081 Leslie S - 1246 Leslie N - 12 Nov. 8 Bathurst - 795 Church - 3945 Leslie S - 335 Nov 10 Spadina - 499 Simcoe - 2300 Yonge - 1641 Church - 845 Sherbourne- 85 Parliament- 322 Leslie S - 1263 Leslie N - 143	2.25 x 10^6 (5.7%)
1-1978 May 27- June 1	May 27-decreasing from 2.3 to 2.0 May 28 to June 1-baseflow 2.0 Higher flows on May 9-7, May 14-24, May 20-7.	No rain during cruise or for 6 days previous May 8-20 rain on and off between 10-15 mm. May 20 May 20 - 7 mm	-	E to SE 41% S to SW 14% W 7% NW-N 16% calm 15%	14.5-8.5 9.5-13 12 14-10	varying about 118 cm above (6.18x10^{6}m^3 or 17.7% above)	-	max. mean	29 21	None (May 13-14 & 20 had overflows)	1.5 x 10^6 . (3.6%)
2-1978 Sept.29- Oct. 3	Sept. 27 to - 29 baseflow 2 Sept.30-baseflow a.m., in p.m. to peak of 44 then decreasing. Oct.1-decreasing to baseflow 2. Oct.2 & 3-baseflow 2. 6 days previous-baseflow. Sept.12-avg. 16 Sept.15-avg. 12 Sept.18-avg. 24	Sept. 30 - 21 mm Sept. 27 - 1 mm Sept. 21 - .5 mm Sept. 10 to 18 - 20 mm to 17 mm on and off.	-	N-NE 10% E-SE 31% S-SW 24% NW-NNW 22% calm 1%	17-10 24-12 19-17 18	varying about 54 cm above (2.83x10^{6}m^3 or 7.9% above)	Sept.28 15°C	max. mean	20 15	Considerable overflows across harbour on Sept. 17 and 18. Sept. 27 Church - 30 Jarvis - 13 Sept.30 - Oct. 1 Wellington- 6550 Bathurst - 1619 Simcoe - 6589 Jarvis - 9092 Sherbourne- 925 Parliament - 1972 Cherry - 1742	1.5 x 10^6 (3.9%)

Table A.2a

Summary of rainfall and runoff during runoff cruise periods, 1976

Cruise	Date	Don R. flow (m^3s^{-1})	Island Rain (mm)	Total Sewer Overflow To Inner Harbour (10^3m^3)
1	760330	3.1		
	760331	15.1	27	29.9
	760401	14.8	2	0.8
	760402	8.0	0.5	
	760403	4.8		
2	760503	4.3		
	760504	2.4		
	760505	2.2		
	760506	11.5	13	40.7
3	760628	2.1		4.8
	760629	13.9	25*	
	760630	15.7	11	14.5
4	760704	6.3		
	760705	3.3		
	760706	2.6		
	760707	4.1	7*	10.8
	760708	5.0	13	3.7
	760709	2.5		

Note*: Don R. watershed rain

Table A.2b

Summary of Rainfall and Runoff During Runoff Cruise Periods, 1977-78

Cruise	Date	Don R. flow (m^3s^{-1})	Island Rain (mm)	Total Sewer Overflow To Inner Harbour (10^3m^3)
3	770626	2.7		
	770627	1.9		
	770628	1.8	19*	
	770629	15.2	24	
4	770831	1.6		
	770901	14.0	20*	57.2
	770902	5.3	3*	
	770903	2.5		
5	771106	1.6		
	771107	34.3	57	24.1
	771108	21.2	2	5.1
	771109	6.3		
	771110	18.4	15	7.1
2	780928	2.2		
	780929	1.7		
	780930	8.4	21*	29.0
	781001	6.4		
	781002	2.1		
	781003	2.0		

Note*: Don R. watershed rain

TABLE A.3

TORONTO HARBOUR WATER QUALITY DATA, CRUISE ONE (760331 - 760403)

MEAN BY ZONE FOR WATER QUALITY PARAMETERS

UPPER NUMBER - MEAN
LOWER NUMBER - STANDARD DEVIATION

UNITS ARE MG/L UNLESS STATED OTHERWISE

PARAMETER	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	PWQO
NH3-N	-	0.036	0.098	0.136	-	0.39	0.02
	-	0.031	0.029	0.052	-	0.24	(UNIONIZED)
TKN	-	0.42	0.51	0.60	-	1.38	
	-	0.10	0.08	0.12	-	0.80	
NO2+NO3-N	-	0.51	0.60	0.69	-	1.28	
	-	0.10	0.05	0.10	-	1.02	
TOTAL P	-	0.046	0.065	0.082	-	0.20	
	-	0.011	0.017	0.031	-	0.12	
FRP	-	0.008	0.017	0.019	-	0.072	
	-	0.002	0.009	0.007	-	0.064	
Si	-	0.29	0.54	0.78	-	2.82	
	-	0.06	0.10	0.26	-	0.63	
COND	-	404.	427.	466.	-	813.	
	-	38.	23.	1.92	-	91.	
CHLORIDE (UMHO/CM)	-	46.6	50.7	58.9	-	135.	
	-	9.3	21.7	9.3	-	40.	
TURBIDITY (FTU)	-	7.65	9.1	14.7	-	31.0	
	-	2.68	3.4	11.7	-	19.5	
SECCHI DISK (M)	-	1.06	0.53	0.44	-	0.200	
	-	0.87	0.16	0.16	-	0.173	
CHL A	-	24.1	19.4	18.4	-	7.40	
	-	11.5	3.6	1.8	-	5.82	

Table A.4a

Means and Standard Deviations of Water Chemistry Data, Toronto Harbour, 1977

Location	Period of Operation	# of Readings	Chloride mg/L		Temperature °C		Dissolved Oxygen mg/l		Dissolved Oxygen % Saturation		Turbidity FTU		pH		Conductivity umho/cm	
			Mean	S.D	Mean	S.D	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
East Gap	Jun 16-Jun 21	357	-	-	13.7	1.4	11.2	1.1	107	11	5.7	3.9	8.3	0.4	362	14
	Jun 23-Jul 9	1151	-	-	13.5	1.9	10.3	2.1	98	21	8.7	6.7	8.1	0.2	356	8
	Jul 15-Jul 28	915	-	-	17.0	2.7	9.2	0.9	95	11	-	-	8.3	0.2	350	17
	Jul 28-Aug 10	935	-	-	15.1	2.5	10.5	1.5	103	12	-	-	-	-	344	7
	Aug 10-Aug 17	501	-	-	20.0	2.0	7.7	0.6	84	7	8.1	4.4	8.0	0.2	344	8
	Aug 24-Sep 1	555	-	-	14.6	2.0	11.6	0.6	114	6	3.5	0.8	8.2	0.1	342	10
West Gap	Jun 16-Jun 28	865	-	-	10.6	2.8	12.2	0.4	109	8	4.5	1.5	8.4	0.2	346	5
	Jun 28-Jul 12	991	-	-	9.8	2.2	11.8	0.5	104	7	5.6	1.7	8.4	0.2	344	4
	Jul 13-Jul 28	1085	-	-	11.0	3.6	12.0	0.7	109	14	4.8	0.6	8.5	0.2	335	3
	Jul 28-Aug 19	1549	-	-	14.4	4.0	10.1	1.6	97	12	4.1	1.1	8.3	0.2	333	6
	Aug 24-Aug 31	520	-	-	12.1	2.9	10.2	0.3	94	5	4.0	0.4	8.2	0.2	332	7
	Aug 31-Sep 9	647	-	-	18.6	0.8	9.0	1.0	94	11	3.5	0.4	8.5	0.1	318	3
Keating Channel	Jun 16-Jun 24	569	123	26	16.6	2.4	7.6	1.5	77	13	-	-	7.7	0.2	546	140
	Jun 24-Jul 13	1365	111	22	17.6	2.3	7.2	1.0	74	9	-	-	7.6	0.2	563	158
	Jul 13-Jul 28	1081	112	25	19.5	3.9	6.3	2.1	68	20	-	-	7.6	0.2	612	187
	Jul 28-Aug 17	1444	105	24	19.9	3.1	7.0	1.3	75	11	-	-	7.6	0.2	554	168
	Aug 17-Aug 31	1001	114	28	17.0	2.1	-	-	-	-	-	-	7.6	0.2	634	185
	Sep 2-Sep 14	874	109	17	20.3	1.1	6.2	1.4	67	14	-	-	7.5	0.1	718	164

Table A.4b

Means and Standard Deviations of Water Chemistry Data, Toronto Harbour, 1978

Location	Period of Operation	# of Readings	Temperature °C		Dissolved Oxygen mg/l		Dissolved Oxygen % Saturation		Turbidity FTU		pH		Conductivity umho/cm	
			Mean	S.D	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
East Gap	Sep 8-12	288	18.2	0.5	8.9	0.3	93.5	3.3	2.7	1.1	8.3	0.1	318	6
	Sep 19-Oct 3	994	17.1	0.6	9.3	0.7	96.2	6.4	6.6	1.5	8.0	0.2	325	5
	Oct 4-Oct 12	576	13.8	1.8	9.2	0.7	87.9	4.4	5.6	2.8	7.9	0.1	326	4
West Gap	Sep 11-Sep 21	707	17.7	0.8	8.2	0.5	85.6	5.1	6.2	2.0	8.0	0.2	306	3
	Sep 21-Oct 12	1511	14.0	3.6	8.9	0.7	85.0	7.0	3.8	1.9	8.0	0.2	312	6
Keating Channel	Sep 8-Sep 17	612	18.5	1.2	6.9	0.7	72.5	7.0	-	-	7.7	0.2	577	187
	Sep 21-Sep 27	435	17.8	0.8	8.5	0.8	89.1	0.7	-	-	-	-	568	112
	Sep 27-Oct 12	1089	15.8	1.9	7.5	1.0	74.8	10.3	-	-	7.6	0.2	619	197

TOTAL PHOSPHORUS (mg /l) Mar. 31 – Apr. 3, 1976

ZONE	MEAN	SD	RANGE	N
○ (small)	.021	.001	.020 – .022	2
○	.060	.011	.034 – .086	50
⊙	.093	.012	.082 – .109	4
⊕	.199	.012	.186 – .209	3

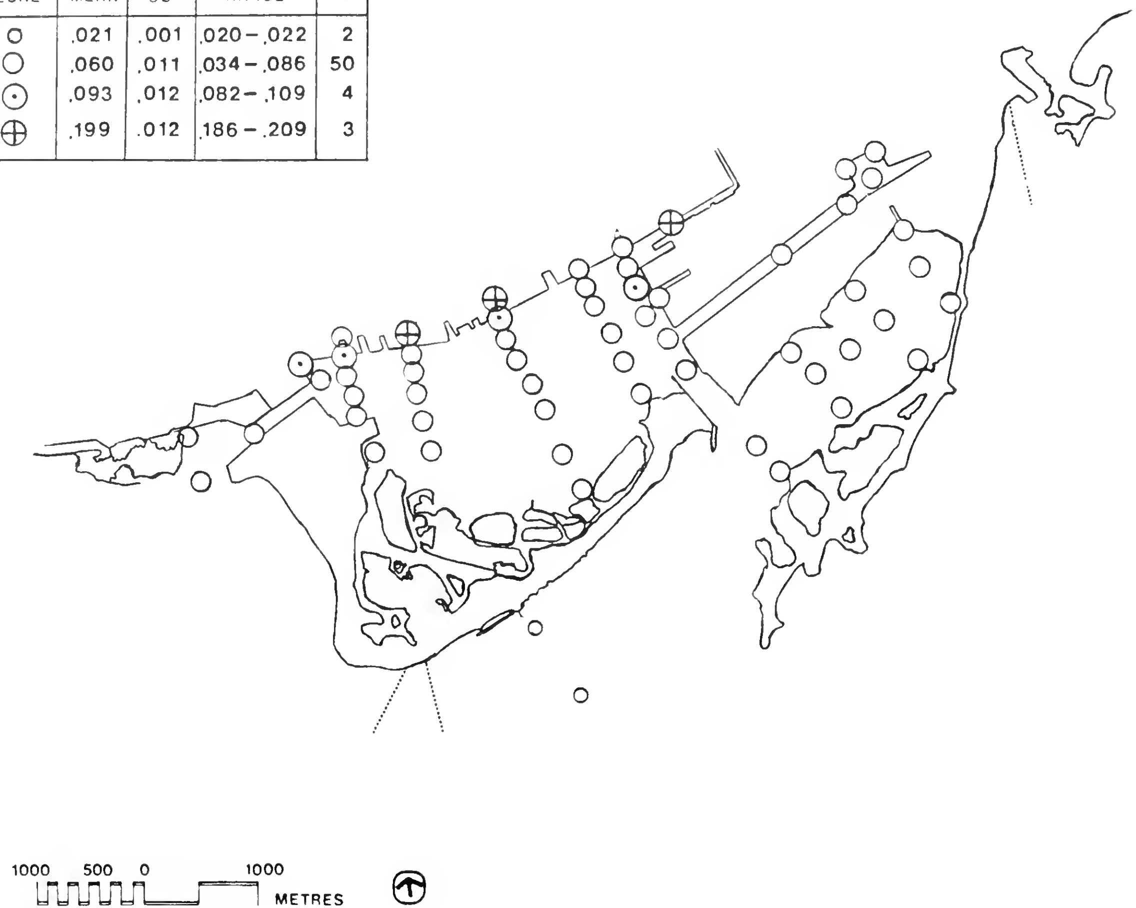

FIGURE A.1 (a)

FILTERED REACTIVE PHOSPHORUS (mg /l) Mar. 31 – Apr. 3, 1976

ZONE	MEAN	SD	RANGE	N
○ (small)	.008	.001	.006 –.010	15
○ (large)	.016	.003	.011 –.023	37
⊕	.050	.026	.024 –.096	9

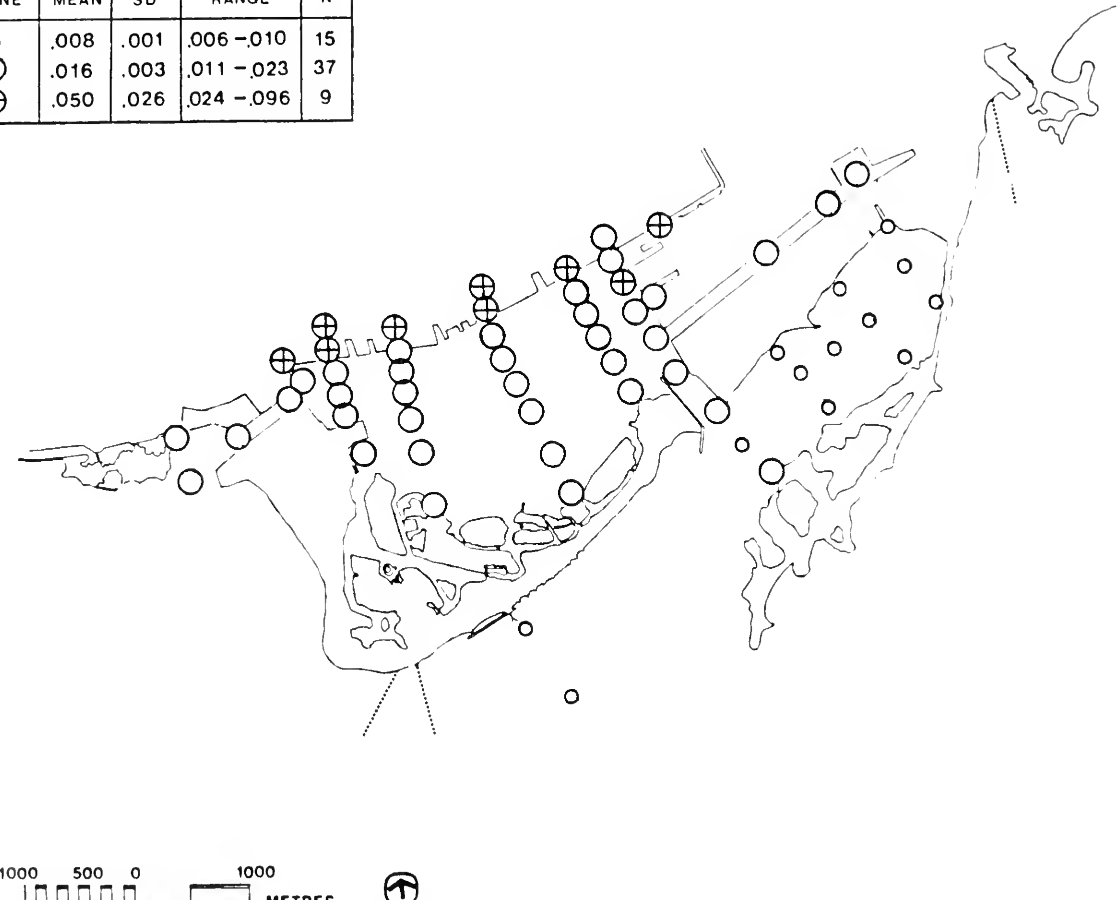

FIGURE A.1 (b)

TOTAL REACTIVE SILICATE (mg /l) Mar.31 – Apr. 3 ,1976

ZONE	MEAN	SD	RANGE	N
○ (small)	.30	.044	.23 – .35	16
○	.51	.065	.37 – .63	30
⊙	.70	.046	.65 – .80	13
⊕	.98			1
●	2.82			1

FIGURE A.1 (c)

CONDUCTIVITY (µS/cm)

Mar. 31 – Apr. 3, 1976

ZONE	MEAN	SD	RANGE	N
∘	341	9	330 – 350	5
○	389	9	378 – 403	8
⊙	427	11	408 – 447	32
⊕	457	6	450 – 467	12
◐	496			1
●	813			1

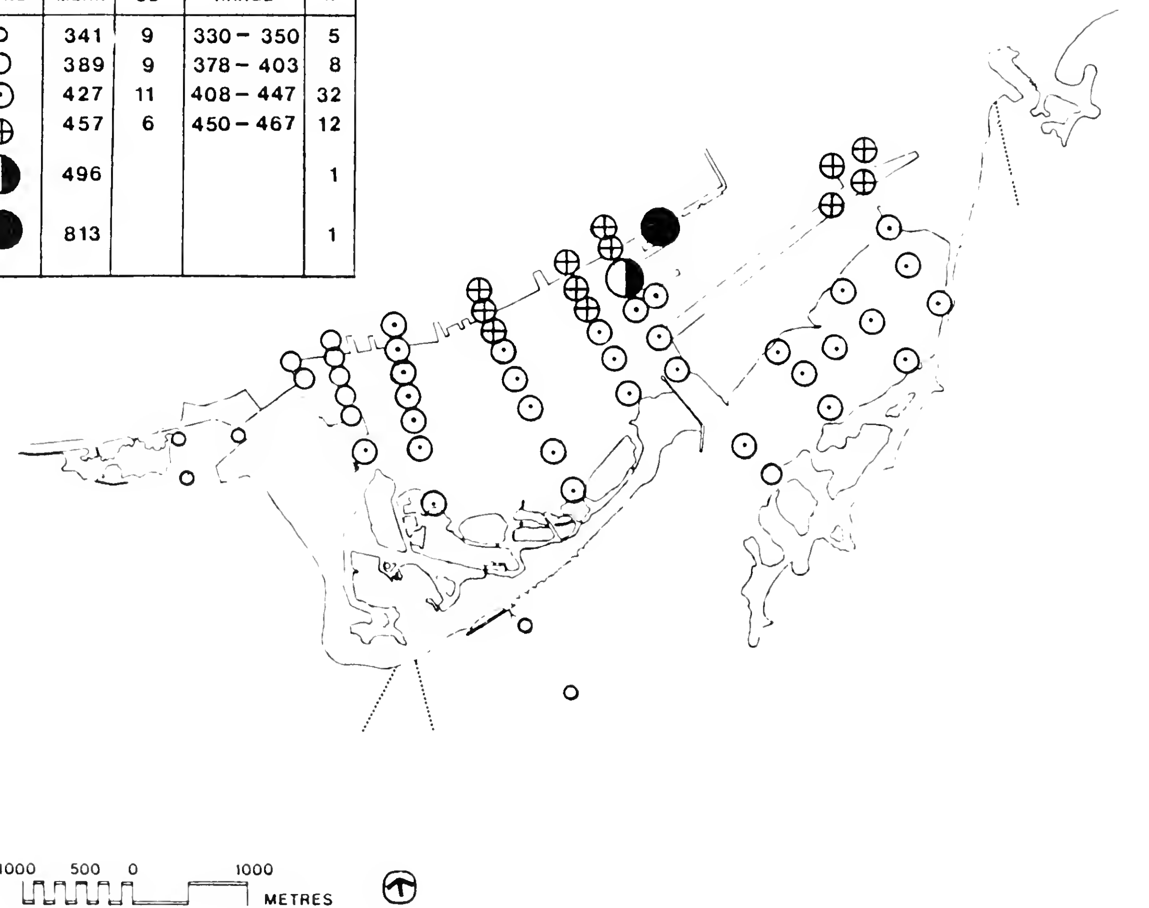

FIGURE A.1 (d)

TURBIDITY (F.T.U)

Mar. 31 – Apr. 3, 1976

ZONE	MEAN	SD	RANGE	N
○	2.4	.68	.9 – 16.0	2
◯	8.5	1.53	5.3 – 12.1	52
⊕	15.6	3.59	12.7 – 22.3	5
●	31.0			1

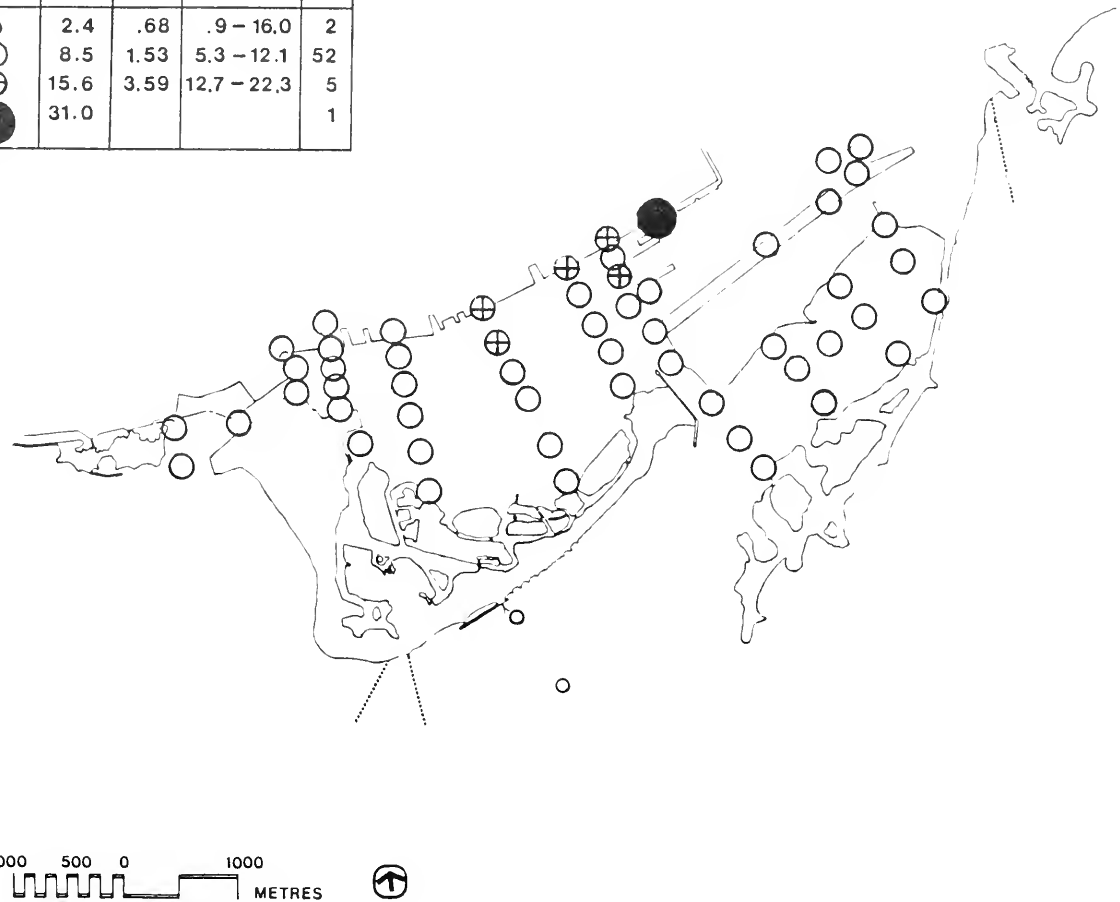

FIGURE A.1 (e)

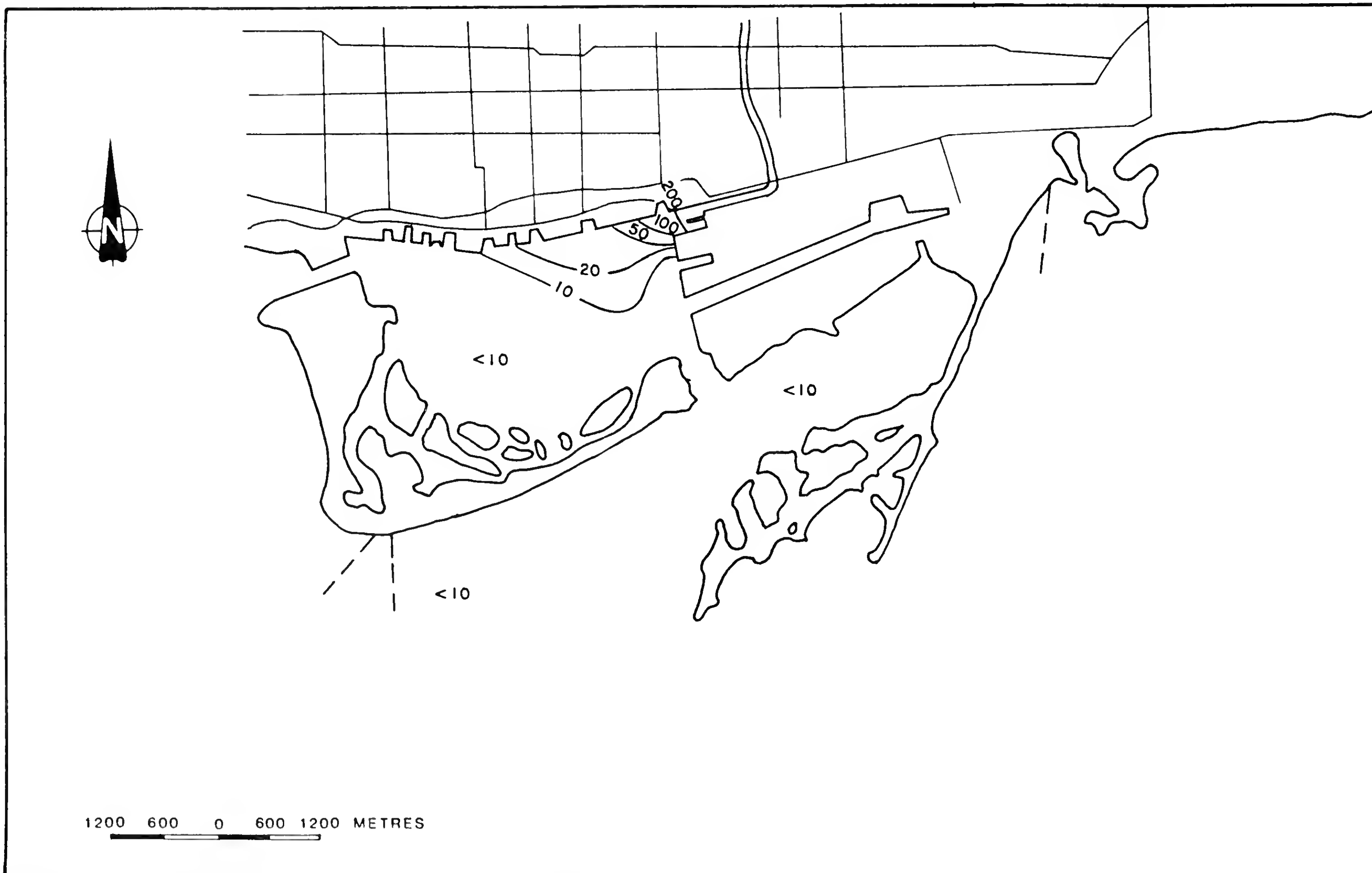

FIGURE A.2 : SPATIAL VARIATIONS OF TURBIDITY OBSERVED UNDER RUNOFF CONDITIONS, JUNE 29, 1977

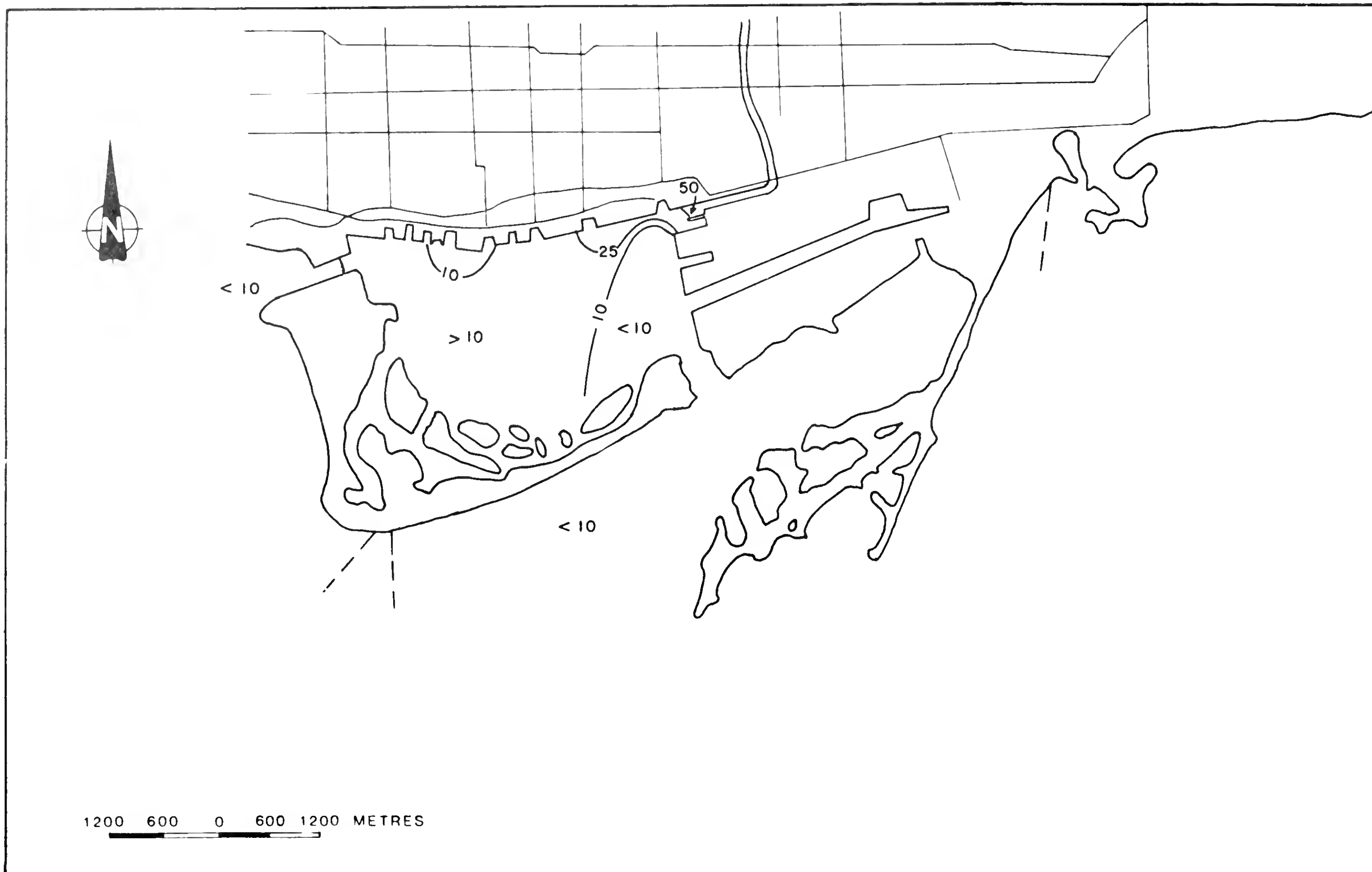

FIGURE A.3 : SPATIAL VARIATIONS OF TURBIDITY OBSERVED UNDER RUNOFF CONDITIONS, SEPTEMBER 2, 1977

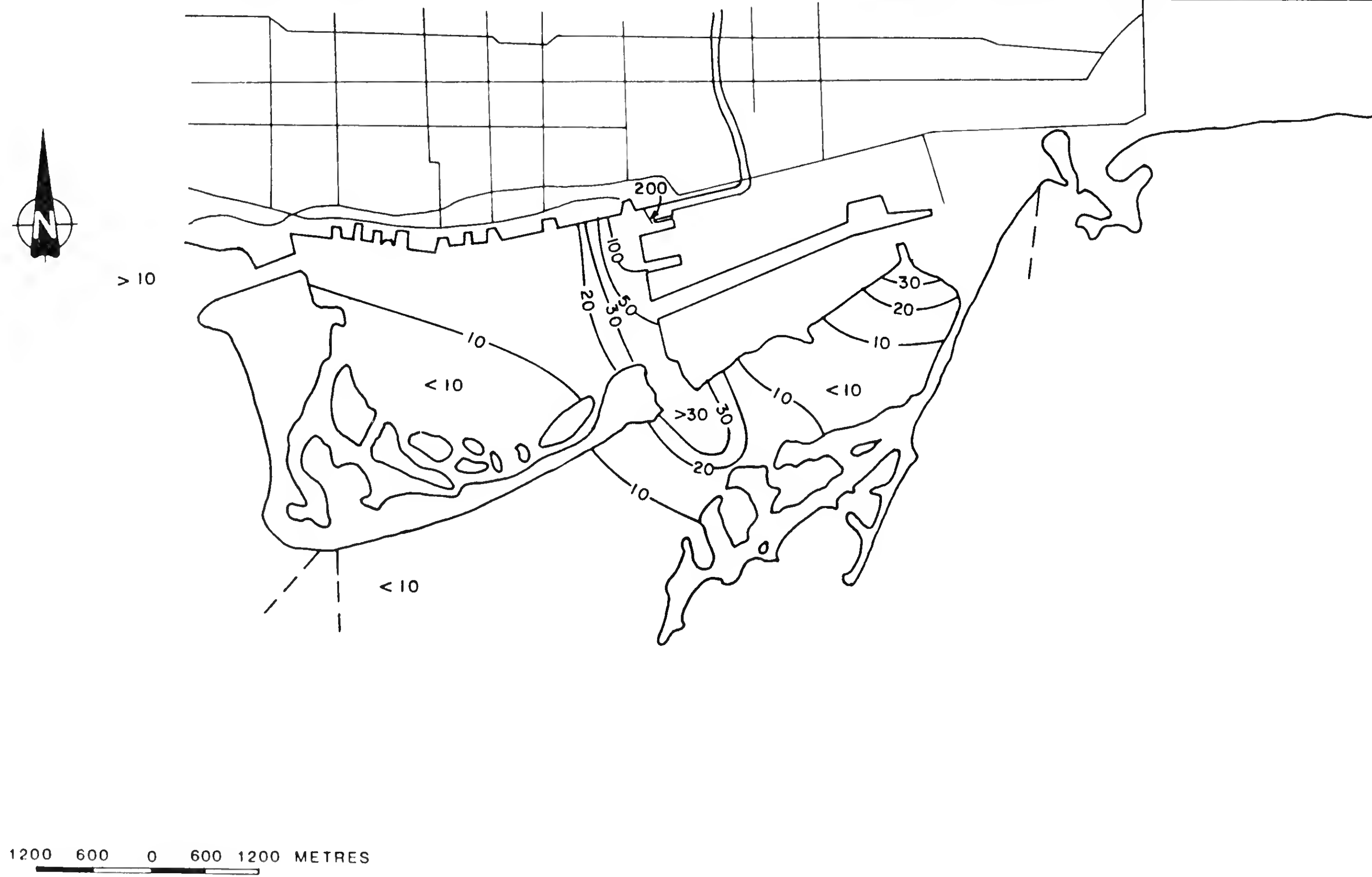

FIGURE A.4 : SPATIAL VARIATIONS OF TURBIDITY OBSERVED UNDER RUNOFF CONDITIONS, NOVEMBER 8, 1977

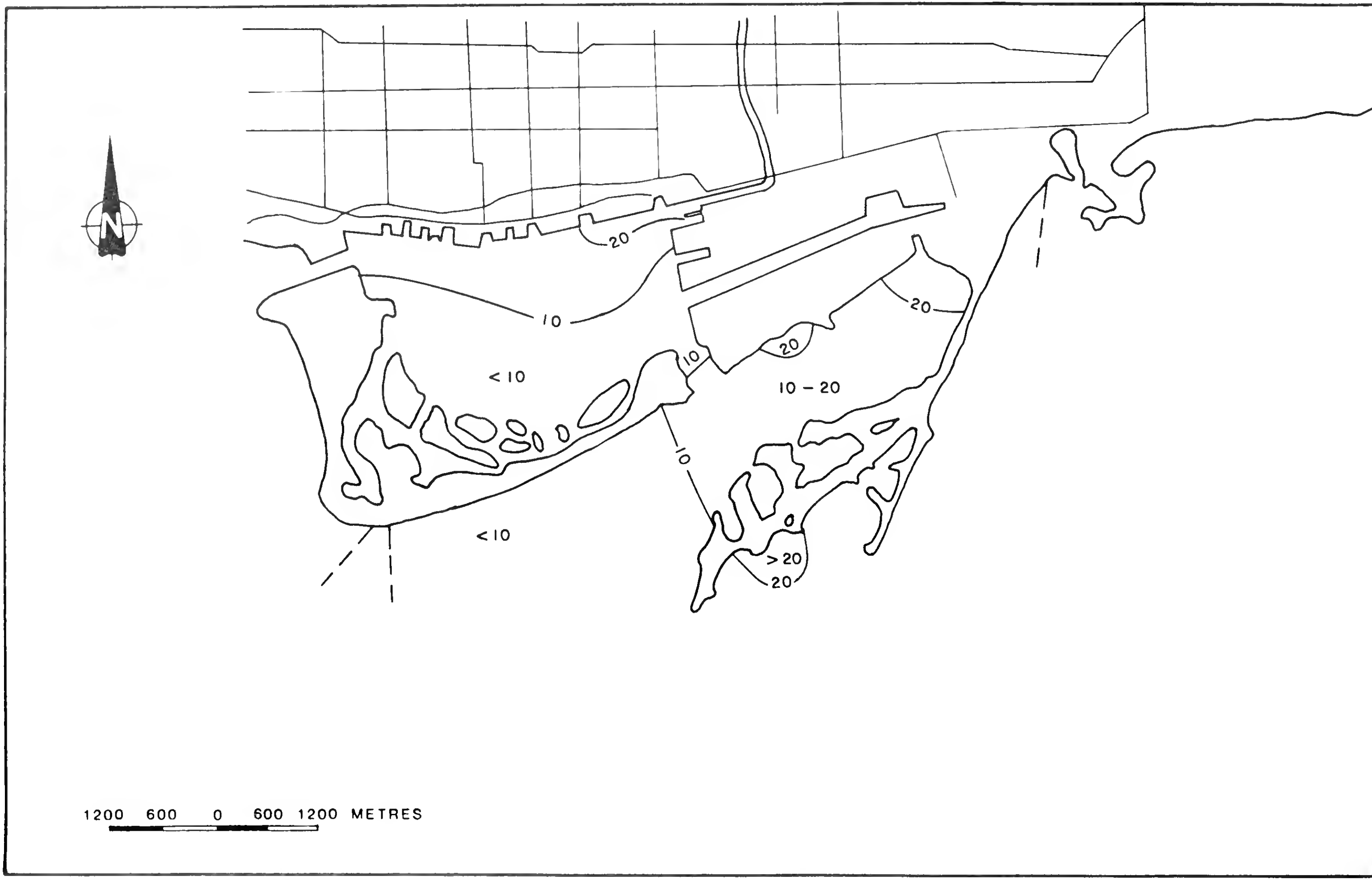

FIGURE A.5 : SPATIAL VARIATIONS OF TURBIDITY OBSERVED UNDER RUNOFF CONDITIONS, NOVEMBER 9, 1977

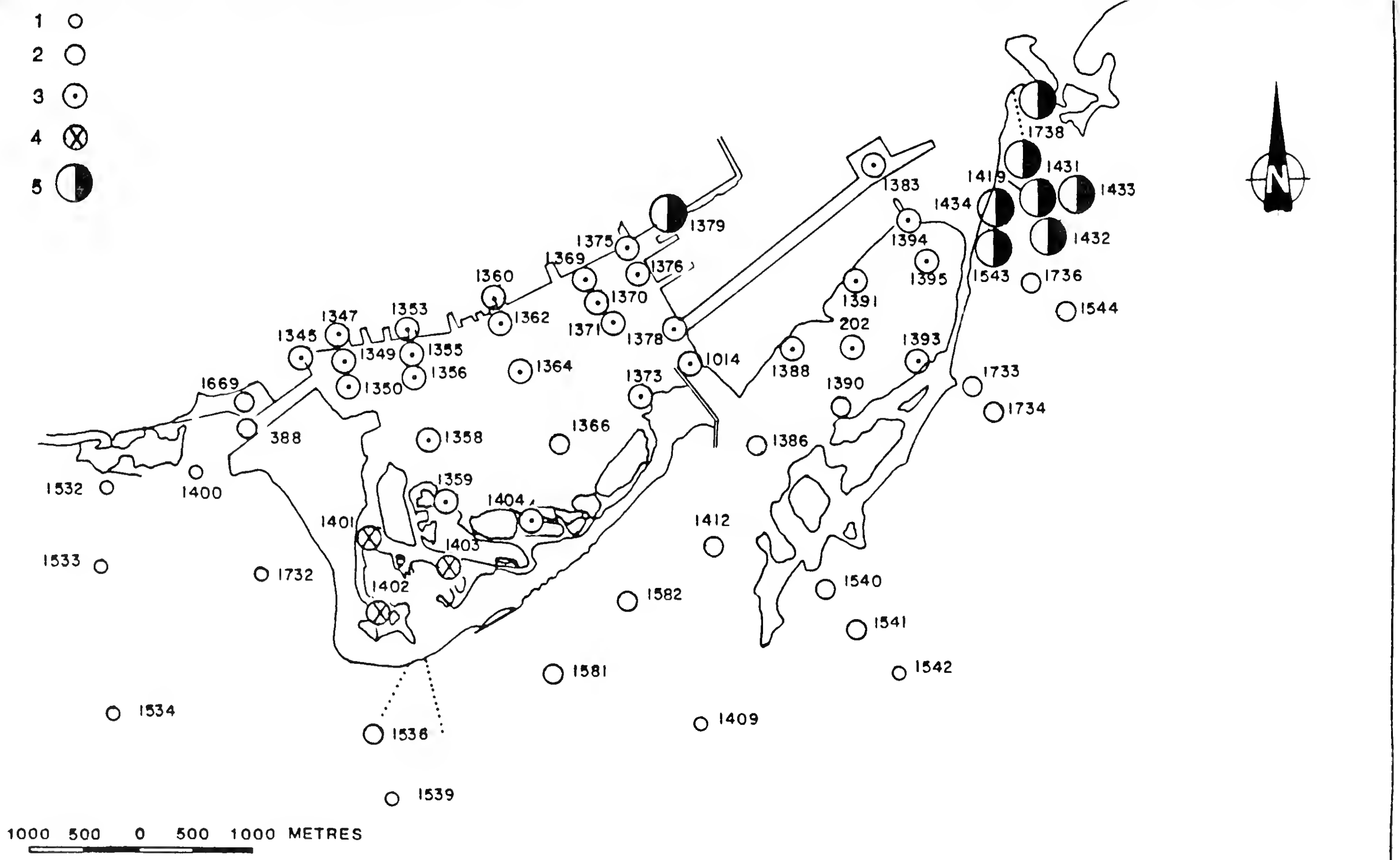

FIGURE A.6 : CLUSTER ANALYSIS OF STATION EFFECTS, SEPTEMBER-OCTOBER 1978 (PART RUNOFF) NH_3 TKN, $NO_2 + NO_3$, TOTAL P, FRP, SI, CONDUCTIVITY, TURBIDITY, SECCHI DISC, TEMPERATURE AND CHLOROPHYLL *a*

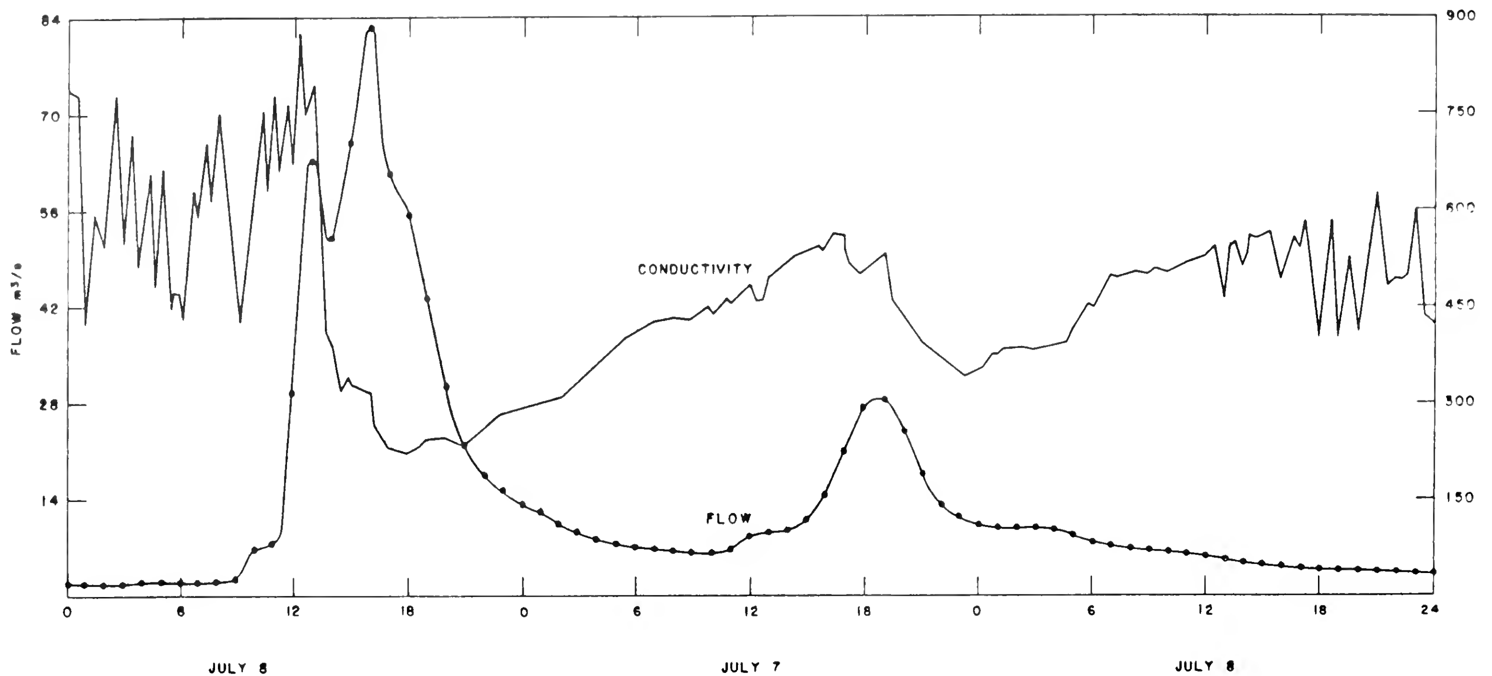

FIGURE A.7 : DON RIVER STREAMFLOW AND KEATING CHANNEL CONDUCTIVITY, JULY 6-8, 1977.